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Analysis of Operational Readiness Rates

DEPARTMENT OF SYSTEMS ENGINEERING AND OPERATIONS RESEARCH CENTER TECHNICAL REPORT

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THE FOLLOWING REPORT DOCUMENTS AN INVESTIGATION OF OPERATIONAL READINESS (OR) RATES PERFORMED BY THE DEPARTMENT OF SYSTEMS ENGINEERING OPERATIONS RESEARCH CENTER (ORCEN) AT THE UNITED STATES MILITARY ACADEMY DURING ACADEMIC YEAR 1997-1998. THE REPORT IS ORGANIZED INTO THREE MAJOR AREAS. THE FIRST AREA PROVIDES A HISTORICAL REVIEW OF THE EVOLUTION OF OR RATES. THE SECOND AREA OF THE REPORT IS AN ANALYSIS OF 24 MONTHS OF OR REPORTS FOR M9 ACE, M1A1, AND CH-47D. THE THIRD MAJOR AREA OF THE REPORT PROVIDES AN INVESTIGATION OF THE CURRENT EQUIPMENT SERVICEABILITY (ES) EVALUATION SYSTEM USED IN THE UNIT STATUS REPORT (USR).

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Executive Summary

The following report documents an investigation of operational readiness (OR) rates performed by the Department of Systems Engineering's Operations Research Center (ORCEN) at the United States Military Academy during academic year 1997-1998.

The report is organized into three major areas. The first area provides a historical review of the evolution of OR rates. In this section we determined how and why the current FMC standards/goals are 90% for all equipment other than aircraft and 75% for aircraft.

The second area of the report is an analysis of 24 months of OR reports for the M9 ACE, M1A1, and CH-47D. The objective of our data analysis was to understand what effect, if any, that several previously unconsidered variables have on a unit's ability to meet the current FMC goals. Through our historical review and data analysis, we identified an appropriate method to establish OR standards for reportable equipment. We recommend using a quality control paradigm to establish equipment serviceability standards based on the historical mean and subsequent levels defined by the number of standard deviations away from the mean. We propose that these standards should be established as a function of equipment type and the potential for deployment of the unit that the equipment is assigned.

The third major area of the report provides an investigation of the current Equipment Serviceability (ES) evaluation system used in the Unit Status Report (USR). We developed four potential alternative ES evaluation systems incorporating our proposed methodology for establishing ES standards. Finally, we identified the alternative system that best satisfies the objective of the ES evaluation system, which is to serve as an indicator of how well a unit is maintaining its on-hand equipment (AR 220-1, Sep. 97, 6-1).

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1 Introduction

1.1 Problem Background

The Office of the Deputy Chief of Staff for Logistics (O/DCSLOG) in conjunction with the Logistic Integration Agency (LIA) requested that the Operations Research Center (ORCEN) conduct a needs analysis for a potential logistics readiness reporting system for the US Army. The analysis of equipment serviceability (ES) standards and operational readiness (OR) goals was executed in support of the Logistics Readiness Needs Analysis study.

One component of a potential logistics readiness reporting system is equipment serviceability. The Army currently uses equipment serviceability ratings in the Unit Status Report (USR) as an indicator of how well a unit is maintaining its on-hand equipment.[1] The rating for a unit's equipment serviceability (R-level rating) is determined by the unit's ability to meet an operational readiness (OR) goal for that particular piece of equipment. The current OR goal for all equipment other than aircraft is 90% Fully Mission Capable (FMC) and 75% FMC for all aircraft. These goals must be met for a unit to obtain an R-1 level rating for equipment serviceability.

A considerable amount of funds and resources must be allocated for a unit to attempt to reach these goals, and, in some cases, it is almost impossible to maintain the equipment at this level. The readiness branch of O/DCSLOG continuously monitors the fleet maintenance status for particular pieces of equipment. A main effort of the readiness branch of O/DCSLOG is to determine why a fleet of equipment fails to meet the current FMC goals. For some equipment, such as the M9 Armored Combat Engineer (ACE) vehicle, the goal is extremely hard to meet, but for others, such as the M1A1 tank, this goal is consistently met or exceeded. These types of problems forced LTC Tracy Ellis, DALO-SMR, to propose the questions: "Are the current FMC standards for ground vehicles and aircraft appropriate? If the standards are no longer appropriate, what should they be?"[2] The same sense of frustration over the goals for OR rates is exhibited in the following email transaction from Brigadier General Lust, USAREUR DCSLOG.

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[1] Army Regulation 220-1, Paragraph 6-1, 1 September 1997.
[2] Quote by LTC Ellis during the initial IPR on 4 February 1998.

"I am in need of the rationale for why the OR rates for ground fleets was set at 90%. I believe knowing the rationale for the 90% OR rate will help us understand why the AH-64 Apache, one of the most lethal weapon systems on the battlefield, has an OR rate of 75%, and the CEV and M35A2 has an OR rate of 90%."[3]

Regardless of the definition of the equipment serviceability rating in AR 220-1, the US Army and Congressional leadership interpret this rating as an indicator of readiness. This confusion over the intent and usage of the equipment serviceability rating is the heart of the problem with the current equipment serviceability evaluation system.

1.2 Project Goals and Objectives

The overall goal for this project was to answer the questions proposed by LTC Ellis: "Are the current FMC standards for ground vehicles and aircraft appropriate? If the standards are no longer appropriate, what should they be?" During an initial background investigation, we determined that there were several key issues that we must address to ensure that we could properly answer the questions. These issues became our major objectives for the project:

- Determine how and why the current R-1 goals are 90% FMC for equipment other than aircraft and 75% FMC for aircraft.
- Understand what effect, if any, that several previously unconsidered variables have on a unit's ability to meet the current FMC goals.
- Understand the current Equipment Serviceability (ES) evaluation process.
- If necessary, propose modified FMC goals/standards and methods for implementation.

2 Historical Review: Evolution of OR Rates

In order to determine how and why the current FMC goals are 90% for ground equipment and 75% for aircraft, and to better understand the current Equipment Serviceability evaluation system, we conducted a historical review of all Army regulations associated with these topics. The Army regulation governing the Unit Status Report (USR) is AR 220-1. Our initial investigation started with this regulation since equipment serviceability criteria are primarily utilized in the USR.

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[3] Email transaction from BG Lust, USAREUR DCSLOG, to MG Sullivan, O/DCSLOG Readiness & Sustainment, 30 November 1997.

2.1 Operational Readiness Goals (AR 220-1)

The oldest copy of AR 220-1 on file in the Pentagon library is dated 23 August 1963. The purpose of this regulation was "to establish uniform operational readiness standards for combat and combat support units of the Active Army and the Army Reserve Components" (AR 220-1, 1963, 1). Operational Readiness was defined as "the state of preparedness of a unit to execute the normal mission reflected in the table of organization and equipment under which the unit is assigned" (AR 220-1, 1963, 1). In 1963, the overall operational readiness condition of the unit was based on a REDCON rating of C1 through C5. The regulation also recognized that "determination of operational readiness of a unit was primarily the judgement of the commander, based upon his knowledge of conditions existing within the unit at any given time." However, the regulation also noted that "there are tangible conditions or factors, which lend themselves to expression and which, when considered together, can be used as indicators of readiness." One of these tangible conditions or factors was equipment serviceability. With respect to equipment serviceability, a REDCON level was obtained based on a unit equipment serviceability profile for mission essential equipment. This profile corresponded to the percentage of GREEN, AMBER, and RED rated equipment in the reporting unit. For example, the profile 851005 corresponds to 85% of a unit's vehicles rated as condition GREEN, 10% of a unit's vehicles as condition AMBER, and 05% of a unit's vehicles in condition RED. Note also that GG+AA+RR = 100%. In order to obtain a unit's profile, the equipment was first inspected and classified as being GREEN, AMBER, or RED using the appropriate Equipment Serviceability Criteria (ESC) scoring from the equipment's technical manuals. The definitions of the color category ratings are related to the likelihood that the equipment will perform "its primary mission for a period of 90 days of operation"[4] into the future.

Guidance for evaluation of serviceability of equipment authorized to units was published in AR 750-10, Maintenance of Supplies and Equipment; Material Readiness (Serviceability of Unit Equipment) dated 1 March 1963. AR 750-57, Maintenance of Supplies and Equipment, Material Readiness Equipment Serviceability Criteria dated 15 August 1968, superseded this regulation, and served the same purpose as AR 750-10. AR 750-57 was subsequently superseded by AR 750-1 dated May 1972. AR 750-1 was the last regulation to provide guidance for evaluation of serviceability of equipment.

It does not appear reasonable to presume that the operational readiness standards pertaining to equipment serviceability as defined in AR 220-1 dated 23 August 1963 arose based on any analytical/engineering design criteria nor equipment requirements needed to execute a wartime mission. These standards seem to be "goals" that were established to serve as indicators of a unit's readiness level only.

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[4] The definition of color category ratings was not clearly defined until the February 1967 issue of AR 220-1.

2.2 Equipment Serviceability (OR) Standards

A search for readiness-related regulations revealed that on 6 December 1968 Army Circular 750-27 (Maintenance of Supplies and Equipment: Equipment Operationally Ready Standards) was published.[5] This circular prescribed "Equipment Operationally Ready Standards for the Material Readiness Reportable Items List, appendix III, TM 38-750." This circular established standards based on "a weighted statistical average representing performance objectives" (AC 750-27, 1968). These standards were expressed as a percentage of possible equipment days in terms of Equipment Operationally Ready (OR) and Not Operationally Ready due to Supply/Maintenance (NORS/NORM). The standards were based on one year's measured average performance as a function of equipment type and major command that the equipment was assigned.[6]

The operationally ready standards found in Army Circular 750-27 were refined by the Equipment Distribution and Condition (EDAC) report compiled by the Army Material Command Logistics Data Center, Lexington, Kentucky. The EDAC report reflected a moving average recomputation by deleting the oldest quarter's data and adding the most recent quarter's data based on a one year time frame. In other words, the standard was refined by computing the average of the four most recent quarterly observations. The common notation for this is a 4-period moving average MA(4) (Nahmias, 61).

AR 750-52 (Equipment Operationally Ready Standards) dated 29 July 1971 superseded Army Circular 750-27. The only major change incorporated in this regulation was that it linked the standards prescribed in this regulation directly to the Unit Status Report. AR 750-52 required major commanders (MACOM) to include an analysis of the reasons for failure to meet the operationally ready standard by 5% or more. The analysis was submitted in the Summary Evaluation of Unit Readiness for the USR as directed by AR 220-1. An additional change in AR 750-52 was an attempt to link a unit's resources to the standards. The following quote illustrates the first attempt to link OR standards to a unit's resources: "The standards prescribed for each command are the minimum objectives consistent with its resources" (AR 750-52, 1971,1).

Neither Army Circular 750-27 nor Army Regulation 750-52 addressed standards for Army aircraft. The earliest regulation referencing aircraft operationally ready standards is AR 710-12 (Army Aircraft Inventory, Status, and Flying Time) dated 10 December 1963.[7] Similar to AR 750-52, the standards established in AR 710-12 were expressed as a function of equipment type and

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[5] A chronological list of regulations pertaining to Equipment Operationally Ready Standards can be found in Appendix A.
[6] An example of ground equipment OR standards can be seen in Appendix B.
[7] A chronological list of regulations pertaining to Equipment Operationally Ready Standards for Army aircraft can be found in Appendix A.

major command.[8] The format for establishment of the standards as a function of equipment type and MACOM is consistent with the standards established for ground equipment reported in Army Circular 750-27. However, AR 710-12 does not state how the aircraft standards were computed. We assume they were computed based on a one year measured average, which is the same methodology used for the ground equipment Operationally Ready standards in Army Circular 750-27.

2.3 Gradual Obfuscation of Standards and Goals

The GREEN/AMBER/RED method of determining equipment serviceability categories that was developed in AR 220-1 dated 23 August 1963 remained relatively the same until the March 1975 issue of AR 220-1. This issue made two subtle changes. The first change is to combine ESC categories GREEN and AMBER into the new category READY. The READY criterion is defined as follows.

> "Equipment capable of performing its primary mission immediately and free of factors which may curtail sustained performance. READY criteria is described and established by equipment serviceability criteria ratings of GREEN and AMBER" (AR 220-1, 1975, D-3).

Conversely, the category NOT READY is the complement of the READY category. Equipment in ESC category RED is deemed NOT READY. The percent of equipment deemed ready represented the sum of the percentages of equipment rated GREEN and AMBER.

The second change in the March 1975 version is based on an optimistic perspective in the assignment of REDCON categories. For example, rather than basing the REDCON rating of C-1 on having less than 11% RED equipment, the 1975 version of AR 220-1 rates equipment status as C-1 if "Not less than 90% of reportable equipment (is) in READY condition." This is the first instance that we see equipment status based on the attainment of 90% READY.

The regulations prescribing the Operationally Ready standards for both aircraft and ground equipment were not affected by this minor change in the interpretation of READY and NOT READY categories for USR status. Computation of the actual OR and NORS/M standards remained the same.

The June 1978 issue of AR 220-1 is the first recorded time the Army used "Operational Readiness" rates based on DA Form 2406 data to report the Equipment Status (ES) ratings. This was the first substantive change in the computation of overall equipment serviceability. Equipment Serviceability for a unit was based on the ratio of available days to possible days by each piece of

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[8] An example of aircraft OR standards from AR 710-12 can be found in Appendix B.

equipment. Earlier reports all used the ratio of the number of pieces of READY equipment to the total number of authorized pieces of equipment.

The Army published AR 11-14 (Logistic Readiness), effective 15 August 1978. This edition coincided with the next revision in AR 220-1. AR 11-14 superseded AR 750-52, which defined Operationally Ready standards for ground equipment. However, AR 11-14 was significantly different from AR 750-52. No longer were the Operationally Ready standards computed from historical data and established as a function of equipment type and major command (MACOM). AR 11-14 defined the logistic readiness goal for each unit reporting under AR 220-1 as "reach an equipment status (ES) rating of READY (C-1)" (AR 11-14,1978, 4). This is significant because the Operationally Ready standard for ground equipment is now aligned with the Operational Readiness goal as defined by AR 220-1. AR 11-14 did caveat the new standard with the following: "It is recognized that the ES goal may not be attained regularly by all units because of external factors" (AR 11-14, 1978, 4). The standard and the goal were linked by the requirement to attain an equipment serviceability (ES) rating of C-1.

AR 700-138 (Army Logistics Readiness and Sustainability) dated 27 December 1985 superseded AR 11-14. The recognition that the ES goal may not be attained in AR 11-14 was not provided in the 18 September 1987 issue of AR 700-138. The goal for ES is now stated as "Reach and sustain an FMC of 90% for all equipment, except aircraft and flight simulators" (AR 700-138, 1987, 4). The operational readiness goal is now fully equivalent to the operational readiness standard for all reportable ground equipment for all intents.

On 2 May 1974, AR 95-33 (Army Aircraft Inventory, Status, and Flying Time) superseded AR 710-12. One of the purposes of AR 95-33 was "to establish the current Army Aircraft Operational Ready Standards" (AR 95-33, 1974, 1). AR 95-33 continued to maintain the individual aircraft standards as a function of aircraft type and major command (MACOM). This method of establishing aircraft operationally ready standards remained until AR 95-33 was discontinued in 1985.

AR 700-138 (Army Logistics Readiness and Sustainability) dated 27 December 1985 superseded AR 95-33. AR 700-138 consolidated all information pertaining to logistical readiness and sustainability. Therefore, AR 700-138 defined the objective of aircraft readiness as follows.

"The objective of aircraft readiness is to achieve a 75% FMC goal at all times. However, because of the wide divergence in complexity and logistic supportability of aircraft systems by Mission Design Series and priorities given to owning units, certain readiness goals are not prescribed at 75% FMC" (AR 700-138, 1985, 9)

AR 700-138 has continued to establish individual aircraft material standards. However, the standards are no longer established based on the

major command (MACOM) to which the aircraft are assigned. The standards are now defined as individual material goals for each type of aircraft.

2.4 Summary & Conclusions

In summary, the 90% FMC standard for ground vehicles has evolved over at least 35 years of use in the USR system. The goal/standard for readiness as defined by AR 220-1 has remained relatively constant since 1963. However, it does not appear reasonable to presume that this standard/goal arose based on any analytic/engineering design criteria, nor is it linked to unit resources or capabilities. We attempted to determine if the standard/goal was based on any operational requirements necessary to execute a unit's assigned missions. However, we could not link Basis of Issue Plans (BOIP) for a new type of equipment or any operational requirements to the standards.[9]

Through evolution of the regulations defining Operationally Ready standards for individual equipment, the standard, in most cases, has been "raised" to meet the goal. The standard is now equivalent to the operational readiness goal as defined by AR 220-1. Regardless of the standard/goal, information provided by units for the USR is an indicator of maintenance status not operational readiness. This final point is well defined in the current definition of the R-level rating as defined in AR 220-1. "The unit status report provides an equipment serviceability (ES) level (R-Rating); this is an indicator of how well a unit is maintaining its on-hand equipment" (AR 220-1, 1997, 30).

3 Data Analysis

In order to understand what effect, if any, that several previously unconsidered variables have on a unit's ability to meet the current FMC goals, we decided to focus our efforts on a small subset of all Army equipment. We conducted a thorough analysis of 24 months of historical data for the M1A1 Abrams Tank, M9 ACE, and the CH-47D helicopter. Our intent was to focus on the following variables:

- **Unit Identity**: Division/Separate Brigade Level.
- **MACOM**: Major Command that a unit is assigned.
- **Group**: This factor categorized units into groups as designated by LTC Ellis, DALO-SMR.
- **Fleet**: This factor categorized units into groups based on the potential for a unit to deploy.
- **Equipment Density**: Quantity on-hand .
- **Usage**: Based on the mileage/flying hours of equipment per month.
- **Age**: Based on the equipment age in years.

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[9] We contacted Mr. Alan Schlie, DSN 676-7236, at Ft Leonard Wood to determine the rationale for the distribution of the M9 ACE to engineer units. We also contacted the Ops Group (Sidewinders) at NTC to determine operational requirements for the M9 ACE.

- **Cost of Repair Parts**: Based on repair part cost at all levels of maintenance.
- **Man-Hours of Repair**: Based on hours of repair at support maintenance levels.

3.1 Data Sources and Limitations

United States Army Material Command Logistics Support Activity (USAMC LOGSA) provided the majority of the data for the analysis of all three pieces of equipment. The data generally covered calendar year 1996 and 1997. The initial data for operationally ready rates was extracted from the Readiness Integrated Database (RIDB).[10] The RIDB data is based on monthly DA Form 2406 reports for ground equipment and monthly DA Form 1352 reports for aircraft. Only active duty Army units were used for the analysis. The subset of active duty Army units used to analyze each piece of equipment is provided in Appendix C.

Repair part cost data was extracted from both the Central Demand Database (CDDB) and the Logistics Intelligence File (LIF).[11] Several problems existed with the linkage of this data to the OR data reported by the units. For example, cost data extracted from the CDDB represented the demands placed on the supply system by a unit for that specific piece of equipment identified by an End Item Code (EIC). However, a unit can place a demand for a part without entering the EIC on the request. The EIC field is not mandatory for the supply request to be processed. Therefore, the CDDB repair part cost data may not accurately reflect the demands placed on the system for that specific piece of equipment. The second problem with the repair part cost data is associated with the data extracted from the LIF database. The query placed on this database represented demands by units for all parts associated with a specific piece of equipment. The problem with this type of a query is that some repair parts are common to other pieces of equipment. Therefore, a demand placed by a unit may not represent a demand for a part needed to repair the piece of equipment of interest. After reviewing the data at hand, we concluded that the demands placed on the supply system for a repair part needed to repair a specific piece of equipment was not accurately reflected. Thus, we decided to remove this variable from our list of factors that we would attempt to use in the analysis.

The data for the number of man-hours of repair in direct support/general support level maintenance was extracted from the Work Order Logistics File (WOLF).[12] The WOLF data does not contain unit level, depot, or contractor maintenance information. It only captures direct support level maintenance. The query placed on this database represented closed work order reports for a

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[10] Point of Contact for the RIDB is Mr. Eric Hinson, LOGSA Readiness & Sustainment Branch; DSN 645-9668

[11] Point of Contact for the CDDB and LIF data is Mr. Paul Pardi, LOGSA; DSN 645-9685.

[12] Point of Contact for the WOLF data is Ms. Lisa Cantu, LOGSA; DSN 645-9660.

specific piece of equipment assigned to a unit. After reviewing the data, we did not feel that the data was sufficiently accurate to support conclusive analysis. We determined that a much more detailed study is needed to link both repair part dollars and manpower to OR reports for a unit.

Usage data for the ground equipment was extracted from the TAAMS Equipment Database (TEDB).[13] The monthly usage data for ground vehicles was limited to the most recent 11 months. This was due to a computer programming constraint at LOGSA. However, we still attempted to link the available data to the unit's OR rates. This constraint was not an issue with the aircraft data. The monthly flying hours were reported on DA Form 1352 found in the RIDB database.

We attempted to address the age of the equipment by extracting the age data from a database maintained by the Cost and Economic Analysis Center (CEAC).[14] The age data provided by CEAC was based on the average age of vehicles assigned to a unit. CEAC extracted their data from reports via the Army Oil Analysis Program (AOAP). The sample size of vehicles used to compute the average age for the units of interest did not match the actual number of vehicles on-hand for the same units. Therefore, there was not a 1:1 relationship between the age data and the OR reports. Due to this limitation, we decided not to address the variable of age in our analysis.

3.2 Assumptions

In the process of developing our approach for the exploratory analysis of OR rates, we made the following assumptions.

- *Effects of Personnel Shortages.* We recognize that the effects of personnel manning are difficult to model because other workload offsets are not effectively measured. In other words, units that are short mechanics will take extraordinary efforts to compensate for the personnel shortages.
- *Unit Funding is Appropriate.* Based on discussions with the principle client, DALO-SMR, we assumed that major commands are sufficiently funded to meet current maintenance requirements.
- *Data supports analysis/modeling of factors affecting OR rates.* In other words, the available data is sufficient for the analysis.
- *Techniques used to model M9, M1A1, and CH47D can be applied to all equipment types.* That is, this subset of equipment is representative of all equipment in the Army.

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[13] Point of Contact for the TEDB is Ms. Anette Reaves, LOGSA; DSN 645-9713.
[14] Point of Contact for the CEAC data is LTC Dave Rogers; DSN 769-3337.

3.3 Methodology

After collecting and reviewing the available data for our study, we determined that the following variables were suitable for our analysis.

- **Unit Identity**: Division/Separate Brigade Level.
- **MACOM**: Major Command that a unit is assigned.
- **Group**: Units were grouped as requested by DALO-SMR.
- **Fleet (Deployability Status of a Unit)**: Units were grouped based on a their potential for deployment.
- **Equipment Density**: Quantity on-hand .
- **Usage**: Based on the mileage/flying hours of equipment per month.

The final objective of our data analysis was to identify an appropriate method to establish equipment serviceability standards given the variables under investigation. The following steps were followed in the analysis of all three pieces of equipment.

1. **Correlation Analysis:** We attempted to determine if there was a statistical relationship between reported OR rates and any of the variables of interest.
2. **Analysis of Variance (ANOVA):** The objective was to determine if there was a statistically significant difference between average reported OR rates based on the variables of interest.
3. **Regression Analysis:** Our objective was to determine if there was a functional relationship between reported OR rates and any of the variables. We attempted to exploit the relationship between reported OR rates and other variables so that we could gain information about OR rates through knowing values of the other variables (Devore, 474).
4. **Time-Series Analysis:** We attempted to use the time-series history of the variable being forecasted (OR Rates) in order to develop a model for predicting future values (Montgomery et. al., 8).

3.4 Results

For ease of presentation, the results of the M9 ACE analysis will be used to guide the reader to our conclusions. The results of the analysis of the other equipment are provided in Appendix C. Table 1 lists the subset of active Army units that were used in the analysis of M9 ACE OR rates.

UNIT	MACOM	Fleet	Group
1st EN Bn/1/1st ID, Ft Riley	FORSCOM	Deployable	3
58th EN Co/11th ACR	OTHER	Non-Deployable	9
23rd EN Bn/1st AD	USAREUR	Deployable	3
40th EN Bn/1st AD	USAREUR	Deployable	3
20th EN Bn/1st CAV	FORSCOM	Deployable	1
8th EN Bn/1st CAV	FORSCOM	Deployable	1
91st EN Bn/1st CAV	FORSCOM	Deployable	1
82nd EN Bn/1st ID, USAREUR	USAREUR	Deployable	3
9th EN Bn/1st ID, USAREUR	USAREUR	Deployable	3
44th EN Bn/2nd ID	EUSA	Deployable	2
2nd EN Bn/2nd ID	EUSA	Deployable	2
70th EN Bn/1st AD, Ft Riley	FORSCOM	Deployable	3
168th EN Bn/3/2nd ID, Ft Lewis	FORSCOM	Deployable	2
43rd EN Co/3rd ACR	FORSCOM	Deployable	1
10th EN Bn/3rd ID	FORSCOM	Deployable	1
11th EN Bn/3rd ID	FORSCOM	Deployable	1
317th EN Bn/3rd ID, Ft Benning	FORSCOM	Deployable	1
299th EN Bn/4th ID	FORSCOM	Deployable	2
1st EN Bde, Ft Leonard Wood	TRADOC	Non-Deployable	0
16th EN Bn/130th EN Bde/V Corps	USAREUR	Deployable	0

Table 1: Units used in the analysis of M9 ACE OR Rates

The units listed in Table 1 are grouped into three categories. The columns identified as MACOM, Group, and Fleet represent categories that were used to group units and attempt to see if there was any effect on the mean OR rate for each category. The category of MACOM is self-explanatory. The Fleet category was developed based on our observation of the potential for deployment of a unit.

3.4.1 Correlation Analysis

We used correlation analysis to determine if there was a statistical relationship between reported OR rates and the following variables: Usage, Aggregate NMCS down-time, Aggregate NMCM down-time, or Quantity of equipment on-hand. Aggregate NMCM/NMCS represents the sum of NMCM/NMCS down-time for the unit divided by the quantity of vehicles on-hand in the unit for that reporting period. This allows a 1:1 relationship between the unit OR report and the Aggregate NMCS/NMCM down-time.

Figure 1 is a correlation matrix output from MINITAB®. The matrix is computed using the Pearson product moment correlation coefficient to measure the degree of linear relationship between two variables (MINITAB® User's Guide, 1-32). For a two-tailed test of the correlation: H_0: $\rho = 0$ versus : H_1: $\rho \neq 0$ where ρ is the correlation between a pair of variables.

```
            QTY O/H  Ag NMCS/  Ag NMCM/  OR RATE
Ag NMCS/  -0.098
           0.042

Ag NMCM/  -0.204     0.004
           0.000     0.940

OR RATE    0.074    -0.535    -0.580
           0.127     0.000     0.000

Usage     -0.181     0.043     0.271    -0.136
           0.032     0.616     0.001     0.112

Cell Contents: Correlation
               P-Value
```

Figure 1: M9 ACE Correlation Matrix

The headings along the top of the matrix and the left-hand side represent variables that were used to determine the amount of correlation between the opposite variable in the matrix. The top value in the matrix represents the correlation (r) value between the two variables. The guideline used to determine the magnitude of correlation between the two variables is as follows: "A reasonable rule of thumb is to say that the correlation is weak if $0 \leq |r| \leq .5$, strong if $.8 \leq |r| \leq 1$, and moderate otherwise" (Devore, 512). Using this rule of thumb, the only variables that are close to moderately correlated with OR rates are Aggregate NMCS and Aggregate NMCM down-time. These values were expected since NMCS and NMCM down-time are used in the computation of OR rates. Therefore, there is not a significant statistical correlation between OR rates and usage of the vehicles (mileage) or the quantity of vehicles on-hand in the unit.

The correlation analysis of the other equipment produced similar results to the M9 ACE correlation analysis. Thus, we concluded that there was not a significant statistical relationship between equipment Usage, Aggregate NMCS/NMCM down-time, quantity on-hand, and a unit's reported OR rates.

3.4.2 Analysis of Variance

A one-way (single-factor) analysis of variance was used to test the equality of population means for each classification or grouping of the units. The grouping of the units were treated as separate factors with various levels associated with each factor. We also used Tukey's Method (also called Tukey-Kramer Method) for multiple comparison of the means to assess the practical differences in means. The null hypothesis for the ANOVA test is that the means are equal. For our test purposes we used an $\alpha = 0.05$ to test the level of

significance of the p-value.   The following figures were extracted from a MINITAB® output.

```
Analysis of Variance for OR RATE
Source      DF        SS        MS       F       P
UNIT        19   15997.3     842.0   10.44   0.000
Error      409   32972.1      80.6
Total      428   48969.4

                                  Individual 95% CIs For Mean
                                  Based on Pooled StDev
Level        N      Mean     StDev    -----+---------+---------+---------+-
10th EN     24    91.463     5.985                            (--*---)
11th EN     24    89.883     5.631                           (---*--)
168th EN    18    75.628     8.780           (-----*---)
16th EN     20    82.440     9.138                 (---*---)
1st EN B    25    80.448     7.475               (--*---)
1st EN B    24    77.037     8.475             (---*---)
20th EN     23    83.374    14.830                  (--*---)
23rd EN     18    88.067     6.456                        (---*---)
299th EN    22    89.323     7.706                       (--*---)
2nd EN B    23    92.161     2.968                          (---*---)
317th EN    20    88.235     6.843                        (---*---)
40th EN     19    87.816     5.537                        (---*---)
43rd EN     23    84.130    16.734                   (---*---)
44th EN     14    84.336     7.806                   (---*----)
58th EN     20    78.045    13.357             (---*---)
70th EN     24    68.629    12.064    (---*--)
82nd EN     23    88.613     2.683                        (---*--)
8th EN B    23    87.252     8.396                      (--*---)
91st EN     22    90.673     7.419                         (---*--)
9th EN B    20    84.180     5.349                   (---*---)
                                      -----+---------+---------+---------+-
Pooled StDev =      8.979            70        80        90       100
```
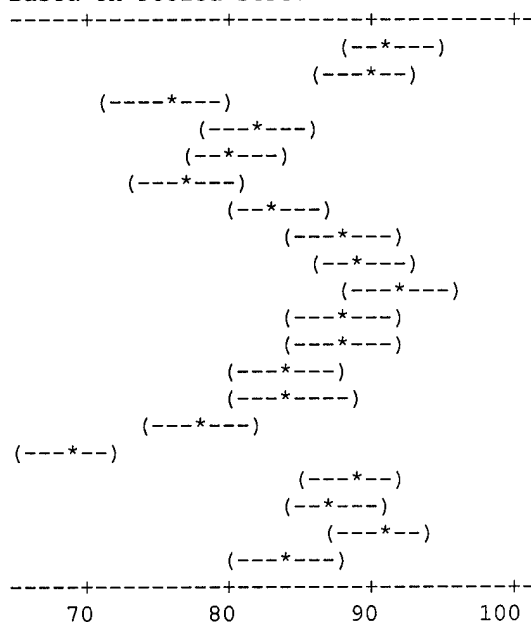
Figure 2: ANOVA for M9 ACE Units with OR Rate as the Response Variable

As shown in Figure 2, the p-Value for the ANOVA is 0.00. Our interpretation of the p-Value is as follows: " The p-Value is the smallest level of significance at which H_0 would be rejected when a specified test procedure is used on a given data set" (Devore, 334). Therefore, at $\alpha = 0.05$ level of significance, we would reject the null hypothesis that all of the means are equal. This difference in means is also graphically illustrated in the confidence intervals provided. Tukey's method for comparison of multiple means is not shown, but the analysis using Tukey's method also portrayed this significant and practical difference in means. However, nothing in this analysis lent itself to establishment of an OR standard based on unit identification.

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Figure 3 illustrates the ANOVA of mean OR Rates based on the MACOM factor. Once again, our interpretation of the P-Value of 0.00 means that not all MACOM mean OR rates are equal. Tukey's Method for multiple comparison of means is shown below the One-Way ANOVA. The output of Tukey's comparison represents a matrix of confidence intervals. MINITAB® presents the results in confidence interval form to allowing assessment of the practical significance of differences among means, in addition to statistical significance. The null hypothesis of no difference between means is rejected if and only if zero is not contained in the confidence interval (MINITAB® User's Guide, 3-7). We did detect a trend developing between what we defined as "deployable" and "non-deployable" units. This trend is shown by the significant difference exhibited in Tukey's comparisons between units that will later be categorized as deployable and non-deployable. For example, the units identified as non-deployable (TRADOC and Other-11th ACR) appear different from the deployable units (EUSA, FORSCOM and USAREUR) mean OR rate shown below.

```
Analysis of Variance for OR RATE
Source      DF       SS        MS        F         P
MACOM        4      2385       596      5.43     0.000
Error      424     46584       110
Total      428     48969
                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
Level        N      Mean      StDev    --------+---------+---------+--------
EUSA        37     89.20       6.50                        (-----*----)
FORSCOM    247     84.18      12.13                   (-*-)
OTHER       20     78.04      13.36    (-------*-------)
TRADOC      25     80.45       7.48       (------*------)
USAREUR    100     86.24       6.48                  (---*--)
                                      --------+---------+---------+--------
Pooled StDev =    10.48             78.0      84.0      90.0
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.00661

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

              EUSA        FORSCOM     OTHER      TRADOC

FORSCOM      -0.03
             10.06

OTHER         3.21        -0.51
             19.10        12.79

TRADOC        1.35        -2.27      -10.99
             16.16         9.74        6.18

USAREUR      -2.55        -5.45      -15.20      -12.19
              8.46         1.33       -1.19        0.60
```

Figure 3: ANOVA of M9 ACE OR Rate Reports based on the MACOM Factor

Figure 4 represents the ANOVA of M9 ACE OR reports based on the Group factor. The group identified as "9" represents the 11th ACR. The same trend as above is illustrated by the lower mean OR rates reported by Groups 9 and 0. These groups represent units that are later categorized as "non-deployable." Tukey's comparison of means reveals that there are significant differences between several of the Group means, but it does not indicate an overall difference between all Groups. Therefore, we concluded that this ANOVA using the Group factor does not lend itself to the establishment of an OR standard.

```
Analysis of Variance for OR RATE
Source      DF        SS        MS         F         P
Group        4      4201      1050      9.95     0.000
Error      424     44768       106
Total      428     48969
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev   ---+---------+---------+---------+---
0           45     81.33      8.22             (-----*-----)
1          159     87.87     10.53                             (--*--)
2           77     86.06      9.34                         (---*----)
3          128     81.81     10.59               (---*--)
9           20     78.04     13.36   (--------*--------)
                                    ---+---------+---------+---------+---
Pooled StDev =     10.28            75.0      80.0      85.0      90.0

Tukey's pairwise comparisons

     Family error rate = 0.0500
Individual error rate = 0.00661

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

                    0            1            2            3

      1         -11.27
                 -1.80

      2          -9.99        -2.09
                  0.53         5.70

      3          -5.34         2.73         0.21
                  4.39         9.39         8.30

      9          -4.25         3.17         0.98        -2.98
                 10.83        16.48        15.06        10.51
```

Figure 4: ANOVA of M9 ACE OR Rate Reports based on the Group Factor

The final ANOVA of M9 ACE OR reports is shown in Figure 5. In this analysis it is clearly identifiable that an OR standard could be established based on the deployability status of a unit. The p-value illustrates the significant difference between the means of each level of the Fleet factor. Tukey's

comparison of means shows the practical difference between the means of each level. Based on this analysis, we felt this factor would allow Army leadership to establish a meaningful standard with an analytical basis. This would allow a separate standard for each level of the Fleet factor, and maintain a "warfighter" approach to the establishment of OR standards.

```
Analysis of Variance for OR RATE
Source      DF        SS        MS       F       P
Fleet        1      1366      1366   12.25   0.001
Error      427     47603       111
Total      428     48969
                                 Individual 95% CIs For Mean
                                 Based on Pooled StDev
Level        N      Mean     StDev  ------+---------+---------+---------+
Deployab   384     85.20     10.57                             (---*---)
Non-Depl    45     79.38     10.44  (----------*---------)
                                    ------+---------+---------+---------+
Pooled StDev =     10.56           78.0      81.0      84.0      87.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.78

Intervals for (column level mean) - (row level mean)

          Deployab

Non-Depl      2.55
              9.09
```

Figure 5: ANOVA of M9 ACE OR Rate Reports based on the Fleet Factor

We also used ANOVA to determine if there was a significant difference between the means for aggregate NMCS/NMCM down-time for each of the factors analyzed above. This analysis is shown in Appendix C. The same results were produced by the ANOVA of aggregate NMCM down-time. However, the ANOVA for aggregate NMCS down-time did not produce a significant difference based on the Fleet factor. We hypothesized that this may be due to the extraordinary efforts taken by O/DCSLOG to assist M9 ACE units trying to attain the current goal of 90% FMC.

One necessary assumption underlying the analysis of variance is that the errors are normally and independently distributed with mean zero and constant variance (Montgomery, 95). In order to assess the adequacy of our models, we checked the normality assumption using the Anderson-Darling Test[15] for normality of the residuals produced by our model. The normality assumption was not met, but "moderate departures from normality are of little concern in the fixed

---

[15] The Anderson Darling test is an ECDF (empirical cumulative distribution function) based test (MINITAB® User's Guide, 1-38).

effects analysis of variance" (Montgomery, 96). We felt the results of our exploratory analysis of the data using ANOVA were relevant since "the analysis of variance (and related procedures such as multiple comparisons) is robust to the normality assumption" (Montgomery, 97).

The analysis of variance for all three pieces of equipment resulted in a statistically significant difference between a deployable and a non-deployable unit's reported OR rates. Based on the results of the ANOVA for all three pieces of equipment, the most appropriate way to establish a standard for all reportable items is based on the deployability criteria of the reporting unit. This will allow the Army leadership to incorporate a "warfighter" perspective for a logistical report.

3.4.3 Regression Analysis

We attempted to predict OR rates and Aggregate NMCM/NMCS down-time for a unit based on the independent or predictor variable of usage of the equipment. The regression procedure used by MINITAB® fits the model using equation 1.

$$Y = \beta_0 + \beta_1 X + \varepsilon$$

Equation 1: Regression Model

The variable Y represents the response variable (OR Rates), X is the predictor variable, β_0 and β_1 are the regression coefficients, and ε is a random error term assumed to have a normal distribution with a mean of zero and a constant standard deviation of σ.

The following figures produced in the analysis represent the tables of coefficients produced by MINITAB®. The tables provide the estimated coefficients along with their standard deviations, a t-value to test whether the null hypothesis of the coefficient is equal to zero, and the p-value for this test (MINITAB® User's Guide, 2-10). The other key information on the table is the R-squared (R^2) value, also called the coefficient of determination. This value represents the proportion of variability in the Y variable accounted for by the predictor variable. R-squared (adj) is an approximately unbiased estimate of the population R^2. This value is adjusted for degrees of freedom in the model.

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```
The regression equation is
OR RATE = 86.5 - 0.0389 Usage

Predictor        Coef       StDev          T          P
Constant       86.507       1.171      73.87      0.000
Usage         -0.03887     0.02428     -1.60      0.112

S = 10.80       R-Sq = 1.8%       R-Sq(adj) = 1.1%
```

Figure 6: Regression Analysis of M9 ACE OR Rates with Usage as the Predictor Variable

Figure 6 represents the results of our attempts to predict a unit's OR rate based on the usage of the M9 ACE. The p-value of 0.112 indicates that there is not sufficient evidence to conclude that the regression coefficient for usage is different from zero for an α level of 0.05 (Type I error rate). Therefore, we conclude that usage is not a valid predictor of OR rates using this data. In other words, there is no linear relationship between usage and OR rates.

```
The regression equation is
Ag NMCS/QTY = 2.29 + 0.00200 Usage

Predictor        Coef       StDev          T          P
Constant       2.2873      0.1923      11.90      0.000
Usage         0.002004    0.003986      0.50      0.616

S = 1.773       R-Sq = 0.2%       R-Sq(adj) = 0.0%
```

Figure 7: Regression Analysis of NMCS down-time for M9 ACE with Usage as the Predictor Variable

Figure 7 illustrates an attempt to predict Aggregate NMCS down-time with Usage of the M9 as a predictor variable. We reached the same conclusion as before based on the p-value of 0.616: there is no linear relationship between usage and Aggregate NMCS down-time.

```
The regression equation is
Ag NMCM/QTY = 0.770 + 0.0127 Usage

Predictor        Coef       StDev          T          P
Constant       0.7699      0.1858       4.14      0.000
Usage         0.012708    0.003852      3.30      0.001

S = 1.713       R-Sq = 7.4%       R-Sq(adj) = 6.7%
```

Figure 8: Regression Analysis of NMCM down-time for M9 ACE with Usage as the Predictor Variable

Figure 8 represents the results of an attempt to predict Aggregate NMCM down-time with usage of the M9 as the predictor variable. The p-value of 0.001 for the regression coefficient of usage is less than our level of significance of $\alpha = 0.05$. Therefore, we reject the null hypothesis that the coefficient is equal to zero. This indicates that usage is a valid predictor of Aggregate NMCM down-time. We must evaluate the R^2 value associated with this regression model. The R-squared and adjusted R-squared value are extremely low. We concluded that the proportion of variability in the data explained or accounted for by the regression model is inadequate. There is a linear relationship between usage and Aggregate NMCM down-time, but the high degree of variability in the data preclude usage from being a sufficiently accurate predictor of Aggregate NMCM down-time.

Before drawing conclusions from any of our models, we conducted an analysis of the residuals produced by each model to determine the adequacy of the least squares fit. We first used the Anderson-Darling test to identify if there was a serious violation of the normality assumption. The plot of the residuals and the Anderson-Darling test concluded that the normality assumption was not met. We then tried to transform the response variables to produce an adequate model using the transformed data. The residuals produced by the transformed regression models also failed to meet the normality assumption.

We also examined the residuals produced by each model using a plot of the residuals versus the data order and tests for autocorrelation to determine if the assumption of independence was violated (Montgomery et al, 33). In all cases, we detected autocorrelation in the residuals, which indicated that we may be able to produce a time-series model. These attempts will be discussed in the next section.

The results of the regression analysis for the CH-47D and the M1A1 are presented in Appendix C. The results are presented in the same format as the M9 ACE. The results produced by the analysis of the M1A1 and CH-47D followed the same pattern as illustrated by the M9 ACE.

Based on the results produced by the regression models for all three pieces of equipment, we determined that it was not feasible to produce an adequate model of the data using regression analysis. We felt that our models did not adequately capture the high degree of variability in the data.

3.4.4 Time-Series Analysis

Our final attempt to forecast OR rates was using time-series analysis. We initially wanted to decompose the time-series into its fundamental components. This would allow us to construct an adequate time-series model of the data. Using the MINITAB® software package for the analysis, we first executed a trend analysis to determine if there was a trend represented in the past 24 months of OR reports.

Trend Analysis for M9 Deployable Unit OR Reports

Linear Trend Model

$Yt = 0.813723 + 2.79E\text{-}03^*t$
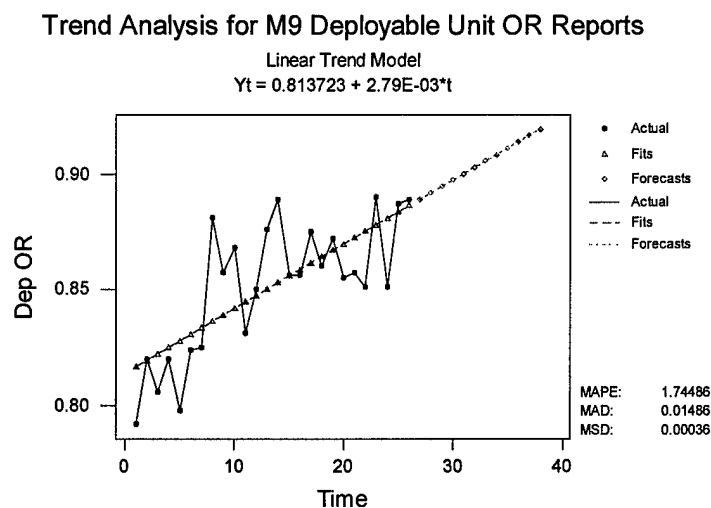
Figure 9: Trend Analysis of the past 24 months of M9 "Deployable" Unit OR Reports

Figure 9 portrays a positive trend in the OR reports for the "Deployable" M9 ACE Unit's OR reports over the past 24 months. LTC Ellis (DALO-SMR) concurred with this result and stated that this represented the results of the extraordinary efforts taken to assist units in an attempt to have the M9 ACE fleet OR rate reach the 90% goal. Figure 9 also portrays a forecast for the next 12 months using the linear trend model. Obviously, this predicts a continuation of the upward trend represented by the past 24 months of OR reports. We did not feel that this type of a forecast based only on the upward linear trend was realistic due to financial constraints placed on the units and engineering design of the equipment. However, this trend should be monitored to see if it continues.

Based on our collective experiences with the field Army, we felt that there may be seasonality present in the data. A seasonal pattern is one that repeats at fixed intervals (Nahmias, 54). We hypothesized that there were fixed intervals of training in a units training schedule; which would illustrate a seasonal pattern in the OR data. In order to check for seasonality in the data, we plotted a time-series graph of both the 1996 and the 1997 monthly OR reports together.

96 & 97 M9 Deployable Unit OR Overlay
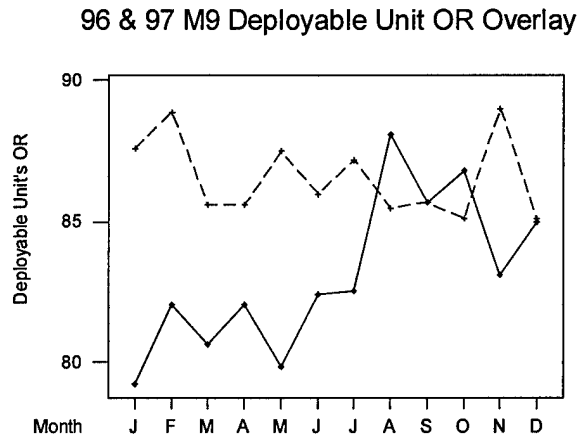
Figure 10: Time-Series Plot of 1996 and 1997 M9 Deployable Unit OR Reports

The solid line and the broken line in Figure 10 represent 1996 and 1997 Deployable Unit OR reports, respectively. The months of January, February and March seem to represent a possible seasonal pattern, but the remaining months do not indicate any seasonality. It is recommended that use of a seasonal series method is based on a seasonal pattern that repeats every N periods, and N must be at least 3 periods (Nahmias, 76). Due to these results, we concluded that there was not enough evidence to support the use of a forecasting method for a seasonal series.

Another time-series related issue that must be addressed is the forecasting period or the basic unit of time for which we want our forecasts to be made. We assumed that the Army's leadership would not be receptive to changing the standards for reportable equipment more than once per year. Given this assumption, our forecasting period is annual. This constraint creates problems due to the fact that we are limited in many cases to only a few annual OR reports. The number of OR reports depends on the length of time the piece of equipment has been in the Army inventory.

Finally, we concluded that there is insufficient evidence to support a time-series forecasting model. This was based on our analysis of potential trend and seasonal methods, and the assumption that our forecast period must be on an annual basis.

3.5 Data Analysis Conclusions

Through our historical review and data analysis, we formulated three significant conclusions. The concept for our first conclusion was founded in our literature search. In our historical review of Army regulations, we found that

equipment serviceability standards were initially defined as a function of equipment type and MACOM. Using this same concept, we wanted to determine if it is still feasible to establish an ES standard for each piece of equipment and how this should be accomplished. Based on the trends exhibited by the analysis of variance for OR rates of the three pieces of equipment, we found the most appropriate way to establish a standard for reportable equipment is based on the deployability criteria of the unit. This type of a standard would also allow the Army leadership to establish a "warfighter" perspective for reporting equipment serviceability.

Once we identified a methodology for determining equipment serviceability standards, we concluded that it is best to redefine that standard on an annual basis. This change to the standard could be published in an annual revision of AR 700-138 or in a stand-alone document of its own. We attempted to forecast or predict OR rates, in order to establish the standards from historical OR reports. Based on our failed attempts to adequately capture the variability represented in the data, we concluded that the best forecasting standard given the data provided is to use the previous year's average OR rate as the predictor for next year's performance.

Our final conclusion was founded upon the dynamic processes involved with maintaining equipment such as random and unpredictable events associated with failures, maintenance, and supply activities. There are numerous factors or variables represented in this process. Some of these factors are identifiable and some are masked by other factors. The convolution of all of these factors or variables makes the process appear to be fully random. Therefore, rather than attempting to forecast OR rates, we recommend a managerial approach using a statistical quality control paradigm. In other words, the standards for equipment should be based on the historical mean and readiness levels be defined by the number of standard deviations away from the mean. This is similar to the control chart theory introduced by Walter Shewhart in the 1930s (Nahmias, 589).

4 Establishment of an ES Standard

We propose that individual ES standards for all reportable equipment should be established. These standards should be derived in a similar manner to the format used by the Army in the early 1960's. However, based on the results of the data analysis, this standard should be a function of the equipment type and deployability criteria of the unit. Although our recommended quality control paradigm is different from the current leadership directed FMC standards, it provides an analytical/statistical basis for establishing these standards. Figure 11 illustrates the application of the methodology of control charts used in Statistical Process Control to develop ES standards for individual pieces of equipment based on historical parameters.
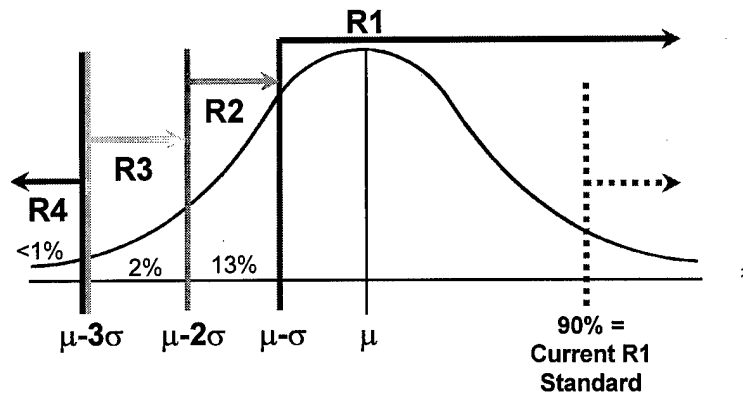
Figure 11: ES Standards developed using the theory of Control Charts

We derived an example of an ES standard for the M9 ACE assigned to a "deployable" unit. This standard was computed using 1996 reported OR rates from "deployable" units. The mean (μ) was 83%, and the standard deviation (σ) was 3%. Using these historical parameters, we established the ES standards provided in Table 2.

Rating/Standard	R-1	R-2	R-3	R-4
Current	100% - 90%	89% - 70%	69% - 60%	< 60%
Proposed	100% - 80%	79% - 77%	76% - 74%	< 74%
Computation	$\{\mu - \sigma\}$	$\{\mu - 2(\sigma)\}$	$\{\mu - 3(\sigma)\}$	$< \{\mu - 3(\sigma)\}$

Table 2: Potential M9 ACE "Deployable " Unit OR Standards derived from 1996 OR Reports

These standards could easily be shifted if the leadership wanted to increase or decrease them. For example, if a piece of equipment has a higher priority, such as a pacing item, then this piece of equipment may have an R-1 standard equal to or even higher than the historical mean (μ). Regardless of how the standard is established, it provides a relevant statistical basis to the development of a standard.

We also investigated how the new standard would categorize the "deployable" fleet in terms of R-Ratings. We used the ES standards derived from the 1996 "deployable" unit OR reports for the M9 ACE and evaluated the 1997 "deployable" unit OR reports. We then compared the R-Ratings from the current OR goals versus the R-Ratings using the proposed ES standards.
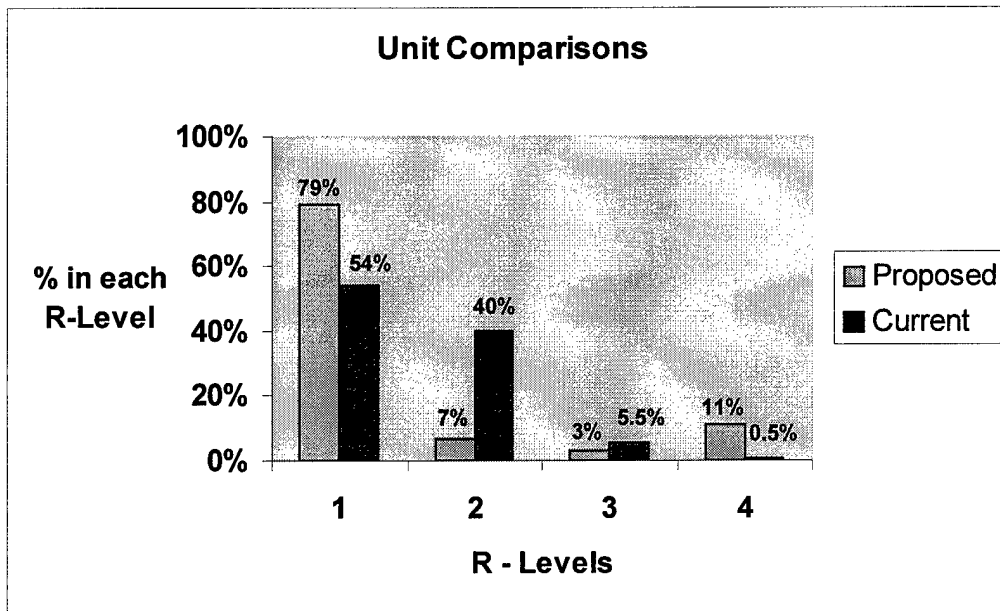
Figure 12: Comparison of Evaluations of 1997 "Deployable" Unit OR Reports using Current & Proposed ES Standards

The unit comparisons in Figure 12 show a significant increase in the percentage of units categorized as R-1. This would relieve the pressure and frustration placed on the units that were just short of the current 90% goal for R-1, but were above the proposed R-1 standard. The majority of the increase in the R-1 level is due to the large decrease in the percentage of units rated R-2 and a small amount from R-3. The most significant change is shown by the increase in the percentage of units categorized as R-4. Applying the quality control paradigm, these units would be classified as being out of statistical control and this variation could be attributable to some special cause.

"At the basis of the theory of control charts is a differentiation of the causes of variation in quality. With the adoption of the statistical point of view, it has come to be recognized that certain variations in the quality of a product belong to the category of chance variations about which little can be done other than to revise the process. Besides chance variations in quality, there are variations produced by "assignable causes". These are relatively large variations that are attributable to special causes" (Duncan, 375).

From a management perspective, these units reporting OR rates that are greater than three standard deviations from the mean should be examined to identify whether there is an "assignable cause" producing this report. The complement to this situation is if the exceptional variation is on the favorable

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side, an effort may be made to extend and perpetuate the cause producing it, (i.e. M9 OR ≥ 92%).

We conducted the same evaluation of proposed ES standards for the M1A1 and CH-47D. These evaluations produced similar results to the M9 ACE evaluation. [16]

5 Alternative ES Evaluation Systems

One of our initial objectives of the study was to develop an understanding of the current ES evaluation system used in the USR. From our study of the current ES evaluation system, data analysis, and historical review we developed five alternative systems including the status quo. The four alternatives to the current system all incorporated the use of individual equipment standards based on historical data for pacing items, and two of the four alternatives expanded the use of historical standards to include all reportable equipment assigned to a unit. The other significant difference in each alternative was based on two key issues.

The first issue is the method of computation and assignment of an R-level for total reportable equipment assigned to a unit. The first method, which is utilized by the current system, computes a cumulative OR rate for all reportable equipment assigned to a unit.

$$\left[\left(\sum AvailableDays \right) \middle/ \left(\sum PossibleDays \right) \right] \times 100\%$$

Equation 2: Current Method for computing FMC % for all Reportable Equipment

---

[16] Appendix D contains the proposed standards and comparisons for all equipment.

The alternative method to Equation 2 is the computation of an average "R-Rating" similar to the computation of a grade point average for a student. The first step in the average R-Rating computation is to assign a weight to each reportable piece of equipment based on the R-level that is assigned to the individual piece of equipment. For example, a piece of equipment evaluated at R-1 based on its historical parameters is assigned a weight of 1, and equipment evaluated at R-2 is assigned a weight of 2. Equation 3 illustrates the computation of the average R-Rating.

$$\frac{[(1 \times \# R - 1LINs) + (2 \times \# R - 2LINs) + (3 \times \# R - 3LINs) + (4 \times \# R - 4LINs)]}{Total \# LINs}$$

Equation 3: Equation for computing Average R-Rating for assignment of Total Equipment R-Level to a Unit

The value computed using the average R-Rating formula is then assigned an R-level for the total reportable equipment assigned to the unit. The R-level is assigned based on the following proposed standards:

R-Level	1	2	3	4
Avg. R-Rating	< 1.5	< 2.5	< 3.5	3.5 or greater

Table 3: Proposed Standards for assignment of R-levels to Average R-Ratings for Total Reportable Equipment assigned to a Unit

The second significant issue in the development of the four alternatives is the treatment of pacing items in the computation of the total reportable equipment R-level. A sub-category of each computation method for total reportable equipment R-levels was derived based on the inclusion or exclusion of pacing items. Table 4 lists all alternative systems and the key attributes associated with each.

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Alternative		Computational Notes
1		Status Quo: The current ES Evaluation System
2: Common Items		All pacing items evaluated by system historical standard; total reportable equipment computation using the cumulative OR rate formula
	A	Total reportable items computation includes pacing items
	B	Total reportable items computation excludes pacing items
3: Common Items		All reportable equipment evaluated by system historical standard; total reportable equipment computation using the average R-Rating formula
	A	Total reportable items computation includes pacing items
	B	Total reportable items computation excludes pacing items

Table 4: Alternative Systems for Evaluation of Equipment Serviceability

5.1 Alternative 1: Status Quo

Our first alternative is to retain the current ES evaluation system. We will discuss this system and all subsequent alternatives by providing an example of an R-Rating computation for a hypothetical unit and then identify the advantages and disadvantages associated with each alternative.

LIN	POSSIBLE*	AVAILABLE*	PACING	PCT	R-LVL
A12345*	60 Days	40 Days	NO	N/A	N/A
B54321*	90 Days	55 Days	NO	N/A	N/A
T13168 M1A1	1740 Days	1620 Days	YES	93%	R-1
H30517 CH-47D	720 Hrs 30 Days	525 Hrs 22 Days	YES (A/C)	73%	R-2
W76473 M9 ACE	210 Days	183 Days	YES	87%	R-2
TOTAL	2130 Days	1920 Days		90%	R-1

Table 5: Current ES Evaluation System

Table 5 was extracted from the current version of AR 220-1 and modified to illustrate our main points. The data in Table 5 identified with an asterisk represents hypothetical data presented in AR 220-1.

The first step in the evaluation process is computing the percentage of Fully Mission Capable (FMC) for each pacing item in the unit. FMC rates are computed by dividing the number of days the item was available to the unit in an FMC status by the number of possible days the item could be available to the unit during the month. The next step is to evaluate the pacing item FMC percentages and assign an R-level to each item. This evaluation is based on leadership directed standards as shown in Table 6.[17]

Level	1	2	3	4
Equip. other than Aircraft	100-90%	89-70%	69-60%	Less than 60%
Aircraft	100-75%	74-60%	59-50%	Less than 50%

Table 6: Current Standards prescribed for R-levels based on percentage of equipment FMC

The next step is to sum all possible and available days for all reportable equipment. Divide the total available equipment days by the total possible equipment days to determine the total equipment percentage FMC. Using Table 6, determine an R-level for total reportable equipment.

The final step is determination of the overall R-level for the unit. Compare the R-level for all reportable equipment to the lowest pacing item R-level. The overall R-level is the lower of the two levels. In this hypothetical example, the lowest rated pacing item is R-2, and the total reportable equipment R-level is R-1. Therefore, the overall unit R-level assigned to the hypothetical unit is R-2.

We identified the following advantages and disadvantages to retaining the current system.

Advantages:
- No changes such as training, regulations, or reporting schemes are required.
- A single leadership directed standard still remains for assignment of an R-1 level for aircraft and other equipment. This standard is the same as the goal for operational readiness.

Disadvantages:
- The current system does not recognize individual equipment differences. For example, the same standard is used for a 35 year old M35A2 and a 9 year old M9 ACE.
- High-density items could strongly influence the total reportable equipment R-level rating. In other words, the use of the cumulative OR method to compute the total reportable equipment R-level allows high-density item such as an M998 to influence the R-level rating.

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[17] The standards are provided in the 1 September 1997 version of AR 220-1 page 30.

- No visibility is given to the maintenance of low-density reportable equipment. In Table 5, the first LIN, A12345*, has an FMC percentage of 67%, but this is not readily visible to leadership using this current evaluation system.
- Pacing items are "double-counted". In other words, pacing items are assigned an R-level individually and then their possible and available days are used again in the cumulative OR computation. If the pacing item is also a high-density item, the inclusion of the pacing item in the cumulative OR computation could mask other maintenance problems within the unit.

5.2 Alternative 2A

This alternative evaluates all pacing items using standards derived from their historical parameters. It also computes the total reportable equipment R-level using the cumulative OR method with the pacing items included. Table 7 provides an example of the evaluation of a hypothetical unit using alternative 2A.

LIN	POSSIBLE*	AVAILABLE*	PACING	PCT	R-LVL
A12345*	60 Days	40 Days	NO	N/A	N/A
B54321*	90 Days	55 Days	NO	N/A	N/A
C45678 M1A1	1740 Days	1620 Days	YES	93%	R-1
H30517 CH-47D	720 Hrs 30 Days	525 Hrs 22 Days	YES (A/C)	73%	R-1
W76473 M9 ACE	210 Days	183 Days	YES	87%	R-1
TOTAL	2130 Days	1920 Days		90%	R-1

Table 7: ES Evaluation of a hypothetical unit using Alternative 2A

The first step in this system is the same as the current system. We compute an FMC percentage for the pacing items, but an R-level is assigned to each pacing item based on a standard derived from the item's historical parameters. The next step is the computation of the total reportable equipment R-level using the cumulative OR method. Once the FMC percentage for total reportable equipment, including pacing items, is computed, we now assign an R-level based on the leadership directed standards shown previously in Table 6.

The final step is determination of the overall R-level for the unit. Compare the R-level for all reportable equipment to the lowest pacing item R-level. The overall R-level is the lower of the two levels. In this hypothetical example, the lowest pacing item R-level is R-1, and the total reportable equipment R-level is R-1 also. Therefore, the overall R-level assigned to the unit is R-1. Based on

this hypothetical example, this is an increase in the overall unit R-level assigned by the current system from R-2 up to R-1.

We identified the following advantages and disadvantages associated with this alternative system.

Advantages:
- There would be few changes required to implement this system. For example, the historical standards for the pacing items could be computed annually by a support agency and disseminated to the field in a document format.
- This system accounts for individual standards for pacing items rather than leadership directed standards.

Disadvantages:
- The system does not take into account individual equipment differences for all reportable equipment.
- High-density equipment items could strongly influence the total reportable equipment R-level.
- No visibility is provided to the leadership for maintenance of low-density reportable equipment items.
- Pacing items are "double-counted". They are used in both the individual equipment R-level computation and in the total reportable equipment computation.
- Computation, publication, and dissemination of pacing item standards is required.

5.3 Alternative 2B

This alternative is similar to alternative 2A, except that the pacing items are not included in the computation of the total reportable equipment R-level.

LIN	POSSIBLE*	AVAILABLE*	PACING	PCT	R-LVL
A12345*	60 Days	40 Days	NO	N/A	N/A
B54321*	90 Days	55 Days	NO	N/A	N/A
T13168 M1A1	1740 Days	1620 Days	YES	93%	R-1
H30517 CH-47D	720 Hrs 30 Days	525 Hrs 22 Days	YES (A/C)	73%	R-1
W76473 M9 ACE	210 Days	183 Days	YES	87%	R-1
TOTAL	150 Days	95 Days		63%	R-3

Table 8: ES Evaluation of a hypothetical unit using Alternative 2B

The first step in this system is the same as presented in alternative 2A. We first compute an FMC percentage for the pacing items, and an R-level is

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assigned to each pacing item based on a standard derived from the item's historical parameters. The next step is the computation of the total reportable equipment R- level using the cumulative OR method. However, this alternative does not include the available and possible days for the pacing items in the cumulative OR computation. Once the FMC percentage for total reportable equipment, excluding pacing items, is computed, we now assign an R-level based on the leadership directed standards shown previously in Table 6.

The final step is determination of the overall R-level for the unit. Compare the R-level for all reportable equipment to the lowest pacing item R-level. The overall R-level is the lower of the two levels. In this hypothetical example, the lowest pacing item R-level is R-1, and the total reportable equipment R-level is R-3. Therefore, the overall R-level assigned to the unit is R-3. Based on this hypothetical example, this is a decrease in the overall unit R-level from the current systems evaluation of R-2 down to R-3.

We identified the following advantages and disadvantages associated with this alternative system.

Advantages:
- There would be few changes required to implement this system. For example, the historical standards for the pacing items could be computed by a support agency and disseminated to the field in a document format.
- The pacing items are no longer "double-counted" in the computation of the total reportable equipment R-level, which provides more visibility to other reportable equipment.

Disadvantages:
- The system does not take into account individual equipment differences for all reportable equipment.
- High-density equipment items could strongly influence the total reportable equipment R-level.
- Computation, publication, and dissemination of pacing item standards are required.

5.4 Alternative 3A

This alternative evaluates all reportable equipment items using standards derived from their historical parameters. Another significant difference from prior alternatives is the computation of the total reportable equipment R-level. This alternative uses the average R-Rating method with the pacing items included. Table 9 provides an example of the evaluation of a hypothetical unit using alternative 3A.

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LIN	POSSIBLE*	AVAILABLE*	PACING	PCT	R-LVL
A12345*	60 Days	40 Days	NO	67%	R-4
B54321*	90 Days	55 Days	NO	61%	R-3
T13168 M1A1	1740 Days	1620 Days	YES	93%	R-1
H30517 CH-47D	720 Hrs –	525 Hrs –	YES (A/C)	73%	R-1
W76473 M9 ACE	210 Days	183 Days	YES	87%	R-1
TOTAL				AVGR	2.0

Table 9: ES Evaluation of a hypothetical unit using Alternative 3A

The first step in this system is the same as the previous alternatives. We compute an FMC percentage for the pacing items, and an R-level is assigned to each pacing item based on a standard derived from the item's historical parameters. The second step is the computation of an FMC percentage for all other reportable equipment, and an R-level is assigned to each item based on a standard derived from the item's historical parameters. The third step is the computation of the total reportable equipment R-level using the average R-rating method. The pacing item R-levels are included in the average R-Rating computation. The R-level for the total reportable equipment is assigned using the standards shown previously in Table 3 on page 25. In this hypothetical example, the average R-rating is 2.0, which is assigned an R-level of R-2.

The final step is determination of the overall R-level for the unit. Compare the R-level for total reportable equipment to the lowest pacing item R-level. The overall R-level is the lower of the two levels. In this hypothetical example, the lowest pacing item R-level is R-1, and the total reportable equipment R-level is R-2. Therefore, the overall R-level assigned to the unit is R-2. Based on this hypothetical example, there is no change in the overall R-level from the current ES evaluation system.

We identified the following advantages and disadvantages associated with this alternative system.

Advantages:
- Individual standards are established for pacing items and all other reportable equipment.
- High-density items influence the final rating equally with low-density items.
- The average R-rating provides more information to the leadership regarding maintenance trends.
- Aircraft FMC percentages can be computed using number of hours rather than converting number of hours to number of days

Disadvantages:

- Pacing items are "double-counted" by including them in the average R-rating computation.
- Computation, publication, and dissemination of standards for all reportable equipment is required.
- Changes will be required in certain regulations. For example, changes will be required to AR 220-1 and AR 700-138.
- Limited visibility is given to the low-density reportable equipment. This lack of visibility is due to the addition of the pacing item R-levels in the average R-rating computation.

5.5 Alternative 3B

This alternative is similar to alternative 3A with respect to the fact that it evaluates all reportable equipment items using standards derived from their historical parameters. The primary difference between alternative 3B and alternative 3A is that alternative 3B does not include the pacing items in the average R-Rating computation for total reportable equipment. Table 10 provides an example of the evaluation of a hypothetical unit using alternative 3B.

LIN	POSSIBLE*	AVAILABLE*	PACING	PCT	R-LVL
A12345*	60 Days	40 Days	NO	67%	R-4
B54321*	90 Days	55 Days	NO	61%	R-3
T13168 M1A1	1740 Days	1620 Days	YES	93%	R-1
H30517 CH-47D	720 Hrs –	525 Hrs –	YES (A/C)	73%	R-1
W76473 M9 ACE	210 Days	183 Days	YES	87%	R-1
TOTAL				AVG R	3.5

Table 10: ES Evaluation of a hypothetical unit using Alternative 3B

The first step in this system is the same as the previous alternatives. We compute an FMC percentage for the pacing items, and an R-level is assigned to each pacing item based on a standard derived from the item's historical parameters. The second step is the computation of an FMC percentage for all other reportable equipment, and an R-level is assigned to each item based on a standard derived from the item's historical parameters. The third step is the computation of the total reportable equipment R-level using the average R-rating method. The pacing item R-levels are not included in the average R-Rating computation. The R-level for the total reportable equipment is assigned using the

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standards shown previously in Table 3 on page 25. In this hypothetical example, the average R-rating is 3.5, which is assigned an R-level of R-4.

The final step is determination of the overall R-level for the unit. Compare the R-level for total reportable equipment to the lowest pacing item R-level. The overall R-level is the lower of the two levels. In this hypothetical example, the lowest pacing item R-level is R-1, and the total reportable equipment R-level is R-4. Therefore, the overall R-level assigned to the unit is R-4. Based on this hypothetical example, there is a decrease in the overall R-level from the current ES evaluation system's assignment of R-2 to R-4. However, it must be emphasized that this hypothetical example was constructed to show the differences between the alternative systems.

We identified the following advantages and disadvantages associated with this alternative system.

Advantages:
- Individual standards are established for pacing items and all other reportable equipment.
- Pacing items are not "double-counted" in the average R-rating computation.
- Greater visibility of other reportable equipment is given to leadership by not including the pacing items in the average R-rating computation.
- High-density items influence the final rating equally with low-density items.
- The average R-rating provides more information to the leadership regarding maintenance trends.
- Aircraft FMC percentages can be computed using number of hours rather than converting number of hours to number of days.

Disadvantages:
- Computation, publication, and dissemination of standards for all reportable equipment are required.
- Changes will be required in certain regulations. For example, changes will be required to AR 220-1 and AR 700-138.

5.6 Summary of Alternative ES Evaluation Systems

The majority of the data used to evaluate the alternative systems was hypothetical and specifically constructed to illustrate the differences between the five alternatives. However, it is unlikely that the Army will realize an arbitrary increase or decrease in ES ratings by choosing to implement any of these alternatives. Table 11 illustrates a comparison of the ES ratings assigned by each alternative system using the same hypothetical unit data.

ALTERNATIVE	LOWEST PACING ITEM	OTHER EQUIPMENT	OVERALL R-RATING
Current System	R-2	R-1	R-2
2a	R-1	R-1	R-1
2b	R-1	R-3*	R-3
3a	R-1	R-2	R-2
3b	R-1	R-4*	R-4

* - Data excludes pacing items.

Table 11: Comparison of ES Ratings by Alternative ES Evaluation Systems

We made the following conclusions from the comparisons shown in Table 11.

- The heavy influence of high-density systems is apparent in the overall R-rating assigned by the current system and alternative 2A.
- Alternatives 2B and 3B provide more information about non-pacing, because pacing items are not influencing the assignment of an R-level to the other equipment.
- Alternatives 2A and 3A illustrate the effect of "double-counting" the pacing items in the overall R-rating, when compared with alternatives 2B and 3B, which do not "double-count" pacing items

Our final conclusion, based on our comparisons, is that alternative 3B provides the most information to Army leadership. We feel this alternative meets the objective of the R-level, which is to serve as "an indicator of how well a unit is maintaining its on-hand equipment". [18]

6 Future Research

It is still uncertain how any of the proposed alternative ES evaluation systems would impact on an actual unit's R-level, and subsequently the C-level rating assigned by the Unit Status Report. We recommend that O/DCSLOG initiate a study to investigate and validate the impact of changing the ES reporting and evaluation criteria by comparing historical ES ratings to that which would have been reported under each of the alternative ES evaluation systems.

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[18] Army Regulation 220-1, Paragraph 6-1, 1 September 1997.

This study would require the computation of new standards for all reportable equipment based on historical parameters. The agency assigned the task would need access to classified historical Unit Status Report data, in order to assess the true impact of each alternative ES evaluation system. We feel that this study could be conducted by either the Logistics Integration Agency (LIA) or the Logistics Support Activity (LOGSA) in coordination with DALO-SMR, O/DCSOPS, the USMA Operations Research Center, and other organizations as required.

Appendix A: Regulations Governing Operationally Ready Standards

Ground Equipment

REGULATION	DATE	TITLE
Cir. No. 750-27	6 Dec. '68	Equipment Operationally Ready Standards
AR 750-52	29 July '71	Equipment Operationally Ready Standards
AR 750-52	20 Sep. '73	Equipment Operationally Ready Standards
AR 750-52	1 July '77	Equipment Operationally Ready Standards
AR 11-14	15 July '78	Logistic Readiness
AR 700-138	27 Dec. '85	Army Logistics Readiness and Sustainability
AR 700-138	17 Dec. '86	Army Logistics Readiness and Sustainability
AR 700-138	18 Sep. '87	Army Logistics Readiness and Sustainability
AR 700-138	30 Mar. '90	Army Logistics Readiness and Sustainability
AR 700-138	16 June '93	Army Logistics Readiness and Sustainability

Aircraft

REGULATION	DATE	TITLE
AR 710-12	10 Dec. '63	Army Aircraft Inventory, Status, and Flying Time
AR 710-12	20 Aug, '65	Army Aircraft Inventory, Status, and Flying Time
AR 710-12	9 Oct. '68	Army Aircraft Inventory, Status, and Flying Time
AR 710-12	21 July '71	Army Aircraft Inventory, Status, and Flying Time
AR 95-33	2 May '74	Army Aircraft Inventory, Status, and Flying Time
AR 95-33	22 Sep. '76	Army Aircraft Inventory, Status, and Flying Time
AR 95-33	1 Dec. '79	Army Aircraft Inventory, Status, and Flying Time
AR 700-138	27 Dec. '85	Army Logistics Readiness and Sustainability
AR 700-138	17 Dec. '86	Army Logistics Readiness and Sustainability
AR 700-138	18 Sep. '87	Army Logistics Readiness and Sustainability
AR 700-138	30 Mar. '90	Army Logistics Readiness and Sustainability
AR 700-138	16 June '93	Army Logistics Readiness and Sustainability

* It is important to note that many of these regulations are not listed in the reference section, but all were used during the literature review.

Appendix B: Examples of Historical OR Standards

Table 12 illustrates the ground OR standards published in AR 750-52 dated 29 July 1971. These standards were derived from historical data. They were established as a function of the equipment type and Major Command (MACOM).

NOMENCLATURE	WORLDWIDE OR NORS NORM:	USCONARC OR NORS NORM:	USAREUR OR NORS NORM:	ARADCOM OR NORS NORM:	USARAL OR NORS NORM:	USARPAC OR NORS NORM:	OTHER OR NORS NORM:	VIETNAM OR NORS NORM:
TANKS								
TANK, COMBAT, M48 SERIES	96 9	5:95 12	5: . .	.: . .	.: . .	.: . .	.:94 11	5:88 6 6
TANK, COMBAT, M60 SERIES	94 11	5:90 12	8:83 8	3:.. .	.: . .	.: . .	.: . .	.: . .
CATEGORY SUMMARY	95 3	7:92 11	7:89 8	3: . .	.: . .	.: . .	.:94 11	5:88 6 6
COMBAT VEHICLES								
HOWITZER, LIGHT, SP, 105MM	96 8	8:92 10	8:92 4	4: . .	.: . .	.: . .	.: . .	.: . .
HOWITZER, MEDIUM, SP, 155MM	86 9	5:92 13	5:89 7	8: . .	.: . .	.: . .	.: . .	.:92 4 4
HOWITZER, HEAVY, SP, 8-INCH	92 13	5:74 16	10:87 5	4: . .	.: . .	.: . .	.:92 4	4:92 4 4
CARRIER, 107MM MORTAR, SP	85 12	3:92 14	4:88 8	4:88 9	4:83 13	4:92 5	3:92 5 3
CARRIER, 81MM MORTAR, FT	90 7	3:92 10	3:89 8	3:85 11	4: . .	.:92 5	3:92 5 3
GUN, F, SP, 175MM	83 12	5:92 10	8: . .	.: . .	.: . .	.: . .	.:92 5 3
GUN, AAA, SP, 40MM	86 9	5:73 12	3: . .	.: . .	.: . .	.: . .	.:92 5 3
RECOVERY VEHICLE, FT, MED	74 17	9:70 19	11:77 18	5: . .	.: . .	.:84 10	6:84 10 6
RECOVERY VEHICLE, FT, LT 4RM	77 17	10:74 19	7:75 20	5:70 22	8:70 22	8:92 10	8:78 13 9
COMBAT ENGR VEHICLE	70 25	5:71 21	8:72 20	8: . .	.: . .	.: . .	.:74 17 9
CARR, PERSONNEL, FT, 43M	90 8	2:96 3	5:90 7	3:85 11	4:85 11	4:92 5	3:92 5 3
ARMORED REC 48 ASSAULT VEHICLE	78 16	6:74 18	8:88 8	4: . .	.:74 18	8:88 8	4:82 4 14
CARR, COMMD & RECON, FT	82 14	4:78 14	8:85 12	3: . .	.: . .	.:81 14	5: . .	.
CARR, COMMD, POST, LT TRACKED	85 7	4:94 9	7:91 7	2:86 8	6:84 9	7:90 8	2:92 4 4
CARR, CARGO, TRACKED, 6-TON	88 8	4:88 8	4:92 6	2: . .	.:70 18	12:88 10	2:81 11 8
CATEGORY SUMMARY	95 11	4:95 9	6:88 8	4:86 8	6:78 16	6:88 10	2:91 5 4

Table 12: Example of Ground OR Standards from AR 750-52

Table 13 illustrates the OR standards for aircraft that were published in AR 710-12 dated 20 August 1965. It was not stated how these standards were computed. We assume they were based on historical data because they are established in the same manner as the ground OR standards.

ARMY AIRCRAFT OPERATIONAL STANDARDS
(Expressed in Percent)

O-1	RVN	Other O/S	Am tng base	Other CONUS	NG
Operationally Ready	87	82	90	83	85
Not Operationally Ready Supply	2	4	2	3	3
Not Operationally Ready Maintenance	11	14	8	14	12
OV-1					
Operationally Ready	68	66	70	66	....
Not Operationally Ready Supply	10	12	10	12	....
Not Operationally Ready Maintenance	22	22	20	22	....

Table 13: Example of Aircraft OR Standards from AR 710-12

Appendix C: Data Analysis

M1A1 Data Analysis

UNIT	UIC	GROUP	MACOM	Fleet
1/11 AR/11th ACR	WG2CAA	9	Other	Non-Deployable
2/37 AR/1ST AD	WAD9AA	3	USAREUR	Deployable
1/1ST AR SQDN/1ST AD	WAETAA	3	USAREUR	Deployable
1/13 AR/3/1ST AD,Ft Riley	WAFZAA	3	Forscom	Deployable
1/35 AR/1ST AD	WAPYAA	3	USAREUR	Deployable
2/70 AR/3/1st AD, Ft Riley	WAZBAA	3	Forscom	Deployable
1/37 AR/1 AD	WH54AA	3	USAREUR	Deployable
1/12TH AR/1ST CAV	WAE0A0	1	Forscom	Deployable
1/12TH AR/1ST CAV	WAE0AA	1	Forscom	Deployable
2/12 AR/1ST CAV	WAGPAA	1	Forscom	Deployable
2/8 AR/1ST CAV	WAGRAA	1	Forscom	Deployable
1/8 AR/1ST CAV	WAGSAA	1	Forscom	Deployable
2/63 AR/1ST ID	WAC6AA	3	USAREUR	Deployable
1/63 AR/1ST ID	WAFXAA	3	USAREUR	Deployable
2/34 AR/1/1ST ID, Ft Riley	WAH0AA	3	Forscom	Deployable
1/34 AR/1/1 ID, Ft Riley	WAKNAA	3	Forscom	Deployable
1/77 AR/1ST ID	WAM8AA	3	USAREUR	Deployable
1/4 AR SQ/1ST ID	WAMVAA	3	USAREUR	Deployable
4/7 AR SQ/2 ID	WAJHAA	2	EUSA	Deployable
1/72 AR/2 ID	WAJVAA	2	EUSA	Deployable
2/72 AR/2 ID	WAJWAA	2	EUSA	Deployable
1/ AR BN/3/2 ID, Ft Lewis	WC01AA	2	Forscom	Deployable
1/33 AR/2 ID, Ft Lewis	WH1KAA	2	Forscom	Deployable
1/3 AR/3rd ACR	WG2LAA	1	Forscom	Deployable
2/3 AR/3rd ACR	WG2MAA	1	Forscom	Deployable
3/3 AR/3rd ACR	WG2NAA	1	Forscom	Deployable
3/7 AR SQ/3 ID	WAP9AA	1	Forscom	Deployable
3/69 AR/3RD ID	WAQ1AA	1	Forscom	Deployable
3/69 AR/3RD ID	WAQ2AA	1	Forscom	Deployable
1/64 AR/3RD ID	WAZDAA	1	Forscom	Deployable
D CO/SPT BN/3rd ID	WDKAD0	1	Forscom	Deployable
4/64 AR/3 ID	WFL9AA	1	Forscom	Deployable
2/69 AR/3 ID	WGM6AA	1	Forscom	Deployable
1/68 AR/4 ID	WAKPAA	2	Forscom	Deployable
3/66 AR/4 ID	WAN7AA	2	Forscom	Deployable
1/10 AR SQ/4 ID	WANZAA	2	Forscom	Deployable
1/66 AR/4 ID	WASHAA	2	Forscom	Deployable
3/67 AR/ 4 ID	WH4GAA	2	Forscom	Deployable
USA ARMOR SCHOOL	W1DXAA	0	Tradoc	Non-Deployable
NATL TNG CTR	W4E6AA	9	Other	Non-Deployable
HQ 1ST AR TNG BDE	W1L4AA	0	Tradoc	Non-Deployable

Table 14: M1A1 Units Evaluated in the Data Analysis

Table 14 lists the active duty M1A1 units that were evaluated during the analysis. This is only a subset of all active duty units that have M1A1s. The

columns identified as MACOM, Group, and Fleet represent categories that were used to group units and attempt to see if there was any effect on the average OR rate for each category. The units identified as "Other" were selected by LTC Ellis. The rationale for this identification was provided earlier in the M9 analysis.

Correlation Analysis

Figure 13 is a correlation matrix output from MINITAB®. The matrix is computed using the Pearson product moment correlation coefficient to measure the degree of linear relationship between two variables (MINITAB® User's Guide, 1-32). For a two-tailed test of the correlation: H_0: $\rho = 0$ versus : $H1$: $\rho \neq 0$ where ρ is the correlation between a pair of variables.

```
           QTY O/H   Ag NMCS   Ag NMCM   OR RATE
Ag NMCS/   0.071
           0.037


Ag NMCM/   0.004     0.126
           0.913     0.000


OR RATE   -0.086    -0.683    -0.720
           0.012     0.000     0.000


USAGE     -0.014    -0.103    -0.127     0.137
           0.853     0.175     0.097     0.072


Cell Contents: Correlation (r)
               P-Value
```

Figure 13: M1A1 Correlation Matrix

The headings along the top of the matrix and the left hand side represent variables that were used to determine the amount of correlation between the opposite variable in the matrix. The top value in the matrix represents the correlation (r) value between the two variables. The guideline used to determine the magnitude of correlation between the two variables is as follows: "A reasonable rule of thumb is to say that the correlation is weak if $0 \leq |r| \leq .5$, strong if $.8 \leq |r| \leq 1$, and moderate otherwise" (Devore, 512). Using this rule of thumb, the only variables that are even moderately correlated with OR rates are Aggregate NMCS and Aggregate NMCM down-time. These values are expected since the NMCS and NMCM down-time are used to compute the OR rate value. Therefore, there is not a significant statistical correlation between OR rates and usage of the vehicles (mileage) or the quantity of vehicles on-hand in the unit.

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Analysis of Variance

A one-way (single-factor) analysis of variance was used to test the equality of population means for each classification or grouping of the units. We also used Tukey's Method (also called Tukey-Kramer Method) for multiple comparison of the means to assess the practical differences in means. The null hypothesis for the one-way ANOVA test is that the means are equal. For our test purposes we used an $\alpha = 0.05$ to test the level of significance of the p-value. The following figures were extracted from a MINITAB® output.

```
Analysis of Variance for OR RATE
Source      DF        SS        MS        F        P
UNIT        13     8282.9     637.1    12.96    0.000
Error      838    41205.5      49.2
Total      851    49488.5
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N       Mean     StDev   ---+---------+---------+---------+---
1/1st ID    50      91.25      3.68                     (-*-)
11th ACR    12      98.12      1.38                           (---*---)
1st AD      65      89.08      9.12                 (-*-)
1st Cav     62      90.93      6.54                  (-*-)
1st ID      88      91.43      7.93                   (*-)
2nd ID      72      92.78      4.54                    (-*)
3/1st AD    49      89.54      4.48                 (-*-)
3/2nd ID    23      91.61      4.97                 (--*-)
3rd ACR     72      94.00      4.83                     (-*-)
3rd ID     167      91.64      8.92                   (*)
4th ID     125      91.42      6.43                   (*-)
AR Schoo    25      89.64      4.85                (--*-)
NTC         16      71.34     11.13    (--*---)
TNG BDE     26      88.95      8.34                 (--*--)
                                    ---+---------+---------+---------+---
Pooled StDev =     7.01          70        80        90       100
```
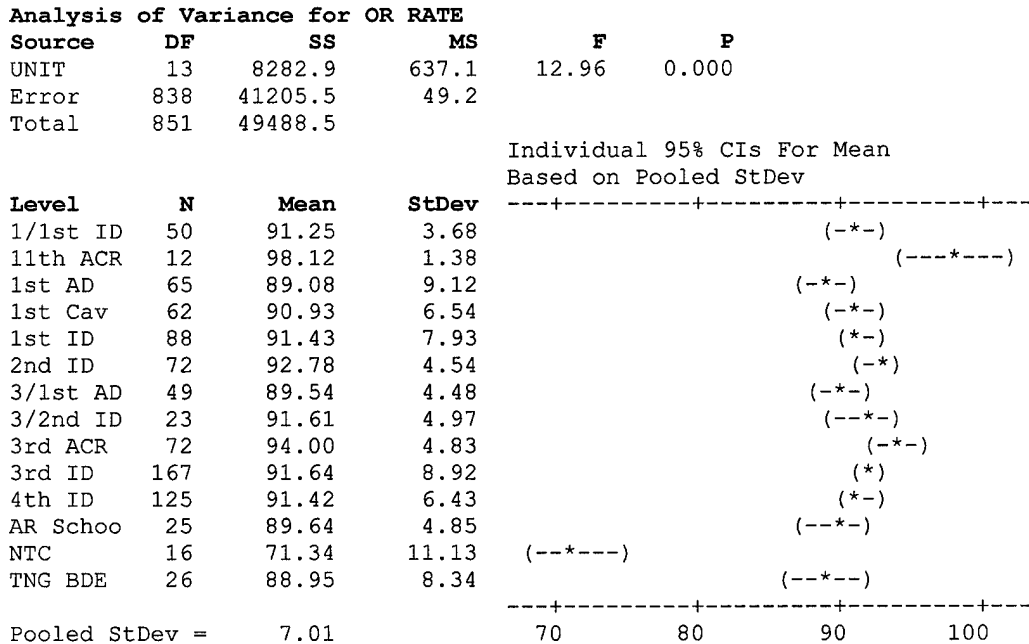
Figure 14: ANOVA of M1A1 OR Reports based on the Unit Factor

41

```
Analysis of Variance for OR RATE
Source      DF        SS        MS        F        P
MACOM        4     2490.0     622.5    11.22    0.000
Error      847    46998.5      55.5
Total      851    49488.5
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev   ----------+---------+---------+------
EUSA        72    92.776     4.544                                  (---*---)
Forscom    548    91.594     6.817                                (-*-)
Other       28    82.818    15.868   (------*------)
Tradoc      51    89.292     6.795                        (----*----)
USAREUR    153    90.433     8.509                           (--*--)
                                    ----------+---------+---------+------
Pooled StDev =    7.449              84.0      88.0      92.0
```

Tukey's pairwise comparisons

```
     Family error rate = 0.0500
Individual error rate = 0.00648

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

              EUSA       Forscom     Other      Tradoc
                                     NTC/11th
Forscom     -1.366
             3.731

Other        5.430        4.837
NTC/11th    14.487       12.715

Tradoc      -0.237       -0.675     -11.256
             7.205        5.278      -1.692

USAREUR     -0.563       -0.698     -11.795     -4.429
             5.249        3.020      -3.436      2.146
```

Figure 15: ANOVA of M1A1 OR Reports based on the MACOM Factor

```
Analysis of Variance for OR RATE
Source      DF          SS          MS          F          P
GROUP        4      2612.3       653.1      11.80     0.000
Error      847     46876.2        55.3
Total      851     49488.5
                                            Individual 95% CIs For Mean
                                            Based on Pooled StDev
Level        N        Mean       StDev    --+---------+---------+---------+----
0           51      89.292       6.795                         (-----*-----)
1          301      92.056       7.713                                 (-*-)
2          220      91.884       5.740                                 (--*-)
3          252      90.422       7.114                               (-*--)
9NTC/11th   28      82.818      15.868     (-------*-------)
                                           --+---------+---------+---------+----
Pooled StDev =      7.439                 80.5      84.0      87.5      91.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00648

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

                    0            1            2            3

        1       -5.839
                 0.310

        2       -5.747       -1.628
                 0.564        1.974

        3       -4.247       -0.099       -0.412
                 1.988        3.368        3.335

        9        1.698        5.227        4.992        3.559
                11.250       13.250       13.140       11.649
```

Figure 16: ANOVA of M1A1 OR Reports based on the Group Factor

```
Analysis of Variance for OR RATE
Source      DF      SS      MS       F       P
Fleet        1    1436.6  1436.6   25.41   0.000
Error      850   48051.9    56.5
Total      851   49488.5
                                 Individual 95% CIs For Mean
                                 Based on Pooled StDev
Level        N     Mean    StDev  ----+---------+---------+---------+--
Deployab   773   91.474    7.033                              (--*--)
Non-Depl    79   86.997   11.246   (-------*-------)
                                 ----+---------+---------+---------+--
Pooled StDev =    7.519           86.0      88.0      90.0      92.0

Tukey's pairwise comparisons

     Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.78

Intervals for (column level mean) - (row level mean)

          Deployab

Non-Depl     2.734
             6.220
```

Figure 17: ANOVA of M1A1 OR Reports based on the Fleet Factor

```
Analysis of Variance for Ag NMCS/
Source      DF      SS      MS       F       P
UNIT         13   212.39   16.34    6.55   0.000
Error       838  2091.36    2.50
Total       851  2303.76
                                 Individual 95% CIs For Mean
                                 Based on Pooled StDev
Level        N     Mean    StDev  ----+---------+---------+---------+--
1/1st ID    50    2.194    0.990                  (--*--)
11th ACR    12    0.317    0.279  (-----*-----)
1st AD      65    2.674    2.644                     (--*-)
1st Cav     62    2.111    1.988                 (--*--)
1st ID      88    1.993    1.491                (-*-)
2nd ID      72    1.597    0.991            (--*-)
3/1st AD    49    2.392    1.333                  (--*--)
3/2nd ID    23    2.222    1.342                 (---*---)
3rd ACR     72    1.418    0.988          (-*--)
3rd ID     167    1.451    1.579          (-*)
4th ID     125    1.810    1.167            (-*-)
AR Schoo    25    2.804    1.905                    (---*---)
NTC         16    3.475    2.182                       (----*----)
TNG BDE     26    2.265    2.493                  (---*---)
                                 ----+---------+---------+---------+--
Pooled StDev =    1.580           0.0       1.5       3.0       4.5
```

Figure 18: ANOVA of M1A1 Aggregate NMCS down-time based on the Unit Factor

44

```
Analysis of Variance for Ag NMCS/
Source      DF        SS        MS        F        P
MACOM        4      57.23     14.31     5.39     0.000
Error      847    2246.52      2.65
Total      851    2303.76
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N       Mean     StDev    ------+---------+---------+---------+
EUSA        72      1.597     0.991    (-------*------)
Forscom    548      1.788     1.438            (--*-)
Other       28      2.121     2.282         (-----------*-------------)
Tradoc      51      2.529     2.219                     (--------*--------)
USAREUR    153      2.282     2.081                (-----*----)
                                        ------+---------+---------+---------+
Pooled StDev =      1.629               1.50      2.00      2.50      3.00
```

Tukey's pairwise comparisons

```
     Family error rate = 0.0500
Individual error rate = 0.00648

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

            EUSA         Forscom      Other        Tradoc

Forscom    -0.748
            0.367

Other      -1.514       -1.195
            0.466        0.528

Tradoc     -1.746       -1.392       -1.454
           -0.119       -0.091        0.638

USAREUR    -1.320       -0.901       -1.075       -0.472
           -0.050       -0.088        0.753        0.966
```

Figure 19: ANOVA of M1A1 Aggregate NMCS down-time based on the MACOM Factor

```
Analysis of Variance for Ag NMCS/
Source      DF        SS        MS        F         P
GROUP        4     92.85     23.21     8.89     0.000
Error      847   2210.91      2.61
Total      851   2303.76
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level        N      Mean     StDev   ---+---------+---------+---------+---
0           51     2.529     2.219                    (--------*-------)
1          301     1.579     1.577   (---*--)
2          220     1.784     1.141      (----*---)
3          252     2.286     1.777               (---*---)
9           28     2.121     2.282        (-----------*-----------)
                                       ---+---------+---------+---------+---
Pooled StDev =     1.616              1.50      2.00      2.50      3.00
```

Tukey's pairwise comparisons

```
     Family error rate = 0.0500
Individual error rate = 0.00648

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

                    0            1            2            3

        1         0.282
                  1.618

        2         0.060       -0.595
                  1.431        0.187

        3        -0.434       -1.083       -0.909
                  0.920       -0.330       -0.096

        9        -0.629       -1.413       -1.223       -0.714
                  1.445        0.329        0.547        1.043
```

Figure 20: ANOVA of M1A1 Aggregate NMCS down-time based on the Group Factor

46

```
Analysis of Variance for Ag NMCS/
Source      DF        SS        MS       F       P
Fleet        1     19.15     19.15    7.12    0.008
Error      850   2284.61      2.69
Total      851   2303.76
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean    StDev   --+---------+---------+---------+----
Deployab   773     1.868    1.567   (---*---)
Non-Depl    79     2.385    2.236             (-----------*------------)
                                    --+---------+---------+---------+----
Pooled StDev =     1.639           1.80      2.10      2.40      2.70
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.78

Intervals for (column level mean) - (row level mean)

           Deployab

Non-Depl      -0.897
              -0.137
```

Figure 21: ANOVA of M1A1 Aggregate NMCS down-time based on the Fleet Factor

```
Analysis of Variance for Ag NMCM/
Source      DF        SS        MS       F       P
UNIT        13    402.41     30.95   13.34    0.000
Error      838   1944.73      2.32
Total      851   2347.14
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean    StDev   ----+---------+---------+---------+--
1/1st ID    50     0.482    0.582     (-*--)
11th ACR    12     0.250    0.397   (---*----)
1st AD      65     0.652    1.128     (-*-)
1st Cav     62     0.666    0.877     (-*-)
1st ID      88     0.632    1.466     (*-)
2nd ID      72     0.608    0.804     (-*-)
3/1st AD    49     0.796    0.722     (-*-)
3/2nd ID    23     0.343    0.498   (--*--)
3rd ACR     72     0.407    0.861    (-*-)
3rd ID     167     1.089    2.577      (*-)
4th ID     125     0.809    1.081      (*)
AR Schoo    25     0.908    1.127     (--*--)
NTC         16     5.306    2.016                          (---*--)
TNG BDE     26     1.935    2.397            (--*--)
                                    ----+---------+---------+---------+--
Pooled StDev =     1.523           0.0       2.0       4.0       6.0
```

Figure 22: ANOVA of M1A1 Aggregate NMCM down-time based on the Unit Factor

```
Analysis of Variance for Ag NMCM/
Source       DF        SS        MS        F        P
MACOM         4      178.00     44.50    17.38    0.000
Error       847     2169.14      2.56
Total       851     2347.14

                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N       Mean      StDev   --------+---------+---------+--------
EUSA        72       0.608     0.804   (---*---)
Forscom    548       0.775     1.616       (-*)
Other       28       3.139     2.969                              (-----*-----)
Tradoc      51       1.431     1.936           (---*----)
USAREUR    153       0.641     1.329    (-*--)
                                    --------+---------+---------+--------
Pooled StDev =       1.600               1.0       2.0       3.0
```

Tukey's pairwise comparisons

```
     Family error rate = 0.0500
Individual error rate = 0.00648

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

              EUSA        Forscom      Other        Tradoc

Forscom      -0.714
              0.381

Other        -3.504       -3.211
             -1.558       -1.518

Tradoc       -1.622       -1.296       0.681
             -0.024       -0.017       2.735

USAREUR      -0.656       -0.265       1.601        0.085
              0.592        0.534       3.397        1.497
```

Figure 23: ANOVA of M1A1 Aggregate NMCM down-time based on the MACOM Factor

```
Analysis of Variance for Ag NMCM/
Source      DF       SS       MS        F        P
GROUP        4    180.52    45.13    17.64    0.000
Error      847   2166.62     2.56
Total      851   2347.14

                                  Individual 95% CIs For Mean
                                  Based on Pooled StDev
Level        N      Mean    StDev   ------+---------+---------+---------+
0           51     1.431    1.936         (---*----)
1          301     0.839    2.023      (*-)
2          220     0.695    0.959    (-*-)
3          252     0.639    1.116    (-*-)
9=NTC/11th  28     3.139    2.969                              (-----*-----)
                                    ------+---------+---------+---------+
Pooled StDev =     1.599             1.0       2.0       3.0       4.0
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.00648

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

                 0          1          2          3

    1        -0.068
              1.254

    2         0.058     -0.243
              1.415      0.531

    3         0.122     -0.173     -0.348
              1.462      0.572      0.458

    9        -2.735     -3.163     -3.321     -3.370
             -0.681     -1.438     -1.569     -1.630
```

Figure 24: ANOVA of M1A1 Aggregate NMCM down-time based on the Group Factor

```
Analysis of Variance for Ag NMCM/
Source      DF       SS        MS        F        P
Fleet        1    121.90    121.90    46.56    0.000
Error      850   2225.24      2.62
Total      851   2347.14
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N     Mean     StDev   --------+---------+---------+--------
Deployab   773    0.733     1.504   (--*-)
Non-Depl    79    2.037     2.476                              (------*------)
                                    --------+---------+---------+--------
Pooled StDev =    1.618               1.00      1.50      2.00

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.78

Intervals for (column level mean) - (row level mean)

         Deployab

Non-Depl      -1.679
              -0.929
```

Figure 25: ANOVA of M1A1 Aggregate NMCM down-time based on the Fleet Factor

Regression Analysis

```
The regression equation is
OR RATE = 89.5 + 0.0132 USAGE

173 cases used 679 cases contain missing values

Predictor        Coef       StDev         T          P
Constant      89.4969      0.7438    120.32      0.000
USAGE        0.013189     0.007274      1.81      0.072

S = 7.613      R-Sq = 1.9%       R-Sq(adj) = 1.3%
```

Figure 26: Regression Model with Usage as the Predictor of M1A1 OR Rates

```
The regression equation is
Ag NMCS/QTY = 1.97 - 0.00183 USAGE

173 cases used 679 cases contain missing values

Predictor          Coef        StDev           T          P
Constant          1.9675       0.1372       14.34      0.000
USAGE            -0.001825     0.001342      -1.36      0.175

S = 1.404        R-Sq = 1.1%       R-Sq(adj) = 0.5%
```

Figure 27: Regression Model with Usage as a Predictor of Aggregate NMCS down-time for the M1A1

```
The regression equation is
Ag NMCM/QTY = 1.25 - 0.00221 USAGE

173 cases used 679 cases contain missing values

Predictor          Coef        StDev           T          P
Constant          1.2450       0.1354        9.19      0.000
USAGE            -0.002214     0.001325      -1.67      0.097

S = 1.386        R-Sq = 1.6%       R-Sq(adj) = 1.0%
```

Figure 28: Regression Model with Usage as the Predictor of Aggregate NMCM down-time for the M1A1

Time-Series Analysis

Trend Analysis of M1A1 Deployable Unit OR Reports
Linear Trend Model
$Yt = 93.564 - 0.139214 \cdot t$
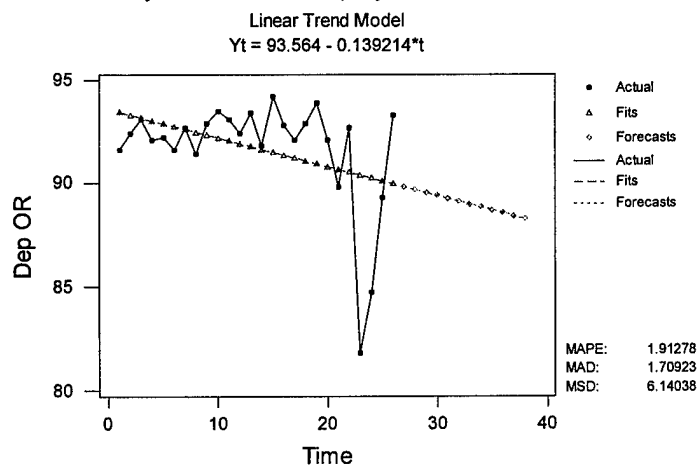
Figure 29: Trend Analysis of M1A1 Deployable Unit OR Reports

96 & 97 M1A1 Deployable Units OR Overlay
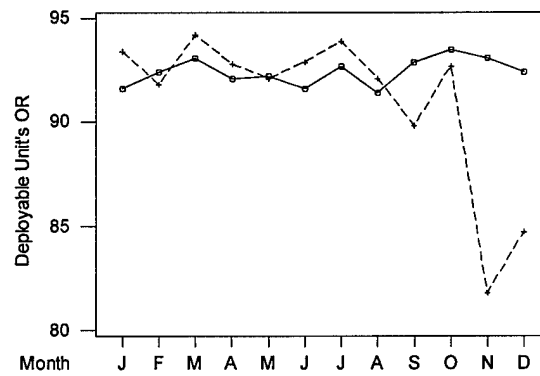
Figure 30: Time-Series Plot of 1996 & 1997 Deployable M1A1 Unit OR Reports

CH-47D Data Analysis

UNIT	MACOM	GROUP	Fleet
A/5/159th/12th AVN Bde, V Corps	USAREUR	3	Deployable
A/2/501st/17th AVN Bde, Korea	EUSA	2	Deployable
B/2/501st/17th AVN Bde, Korea	EUSA	2	Deployable
A/2-159th/18th AVN Bde, Ft Bragg	FORSCOM	1	Deployable
B/2-159th/18th AVN Bde, HAAF	FORSCOM	1	Deployable
10th AVN Regt, Ft Rucker	TRADOC	0	Non-Deployable
3/160th SOAR, HAAF	SOCOM	1	Deployable
B Co/214th/45th CSG	USARPAC	2	Deployable
7th Bn/101st (-)	FORSCOM	1	Deployable

Table 15: CH-47D Units used to Analyze OR Rate Reports

Correlation Analysis

```
          QTY O/H    Ag NMCS/  Ag NMCM/ Usage/QTY
Ag NMCS/   0.098
           0.192

Ag NMCM/  -0.137      0.160
           0.068      0.033

Usage/QT   0.317      0.167     0.280
           0.000      0.026     0.000

OR RATE    0.091     -0.466    -0.900    -0.313
           0.230      0.000     0.000     0.000

Cell Contents: Correlation
               P-Value
```

Figure 31: Correlation Analysis for CH-47 D Data

Figure 31 is a correlation matrix output from MINITAB®. The matrix is computed using the Pearson product moment correlation coefficient to measure the degree of linear relationship between two variables (MINITAB® User's Guide, 1-32). For a two-tailed test of the correlation: H_0: $\rho = 0$ versus : H_1: $\rho \neq 0$ where ρ is the correlation between a pair of variables.

The headings along the top of the matrix and the left-hand side represent variables that were used to determine the amount of correlation between the opposite variable in the matrix. The top value in the matrix represents the

correlation (r) value between the two variables. The guideline used to determine the magnitude of correlation between the two variables is as follows: "A reasonable rule of thumb is to say that the correlation is weak if $0 \le |r| \le .5$, strong if $.8 \le |r| \le 1$, and moderate otherwise" (Devore, 512). Using this rule of thumb, the only variable that is strongly correlated with OR rates is Aggregate NMCM down-time. LTC Ellis (DALO-SMR) expressed that this value was expected due to the history of maintenance related issues with the CH-47D.

Analysis of Variance

A one-way (single-factor) analysis of variance was used to test the equality of population means for each classification or grouping of the units. The grouping of the units were treated as separate factors with various levels associated with each factor. We also used Tukey's Method (also called Tukey-Kramer Method) for multiple comparison of the means to assess the differences in means. The null hypothesis for the test is that the means are equal. For our test purposes we used an $\alpha = 0.05$ to test the level of significance of the p-value. The following figures were extracted from a MINITAB® output.

```
Analysis of Variance for OR RATE
Source      DF        SS         MS        F        P
UNIT         8   10626.7     1328.3    17.82    0.000
Error      169   12597.6       74.5
Total      177   23224.3
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level        N      Mean      StDev    ---------+---------+---------+-------
10th AVN    23    55.165      5.637    (--*---)
3/160th      6    69.933      9.413                (------*------)
7/101st     24    78.346      6.025                            (--*---)
A/2/501s    23    73.896      7.842                       (---*--)
A/2-159t    20    71.605      8.860                    (---*--)
A/5/159t    23    74.178      6.638                       (--*---)
B Co/214    14    57.543     19.296     (----*---)
B/2/501s    23    74.343      7.579                       (--*---)
B/2-159t    22    75.027      5.784                       (---*---)
                                       ---------+---------+---------+-------
Pooled StDev =     8.634                        60        70        80
```
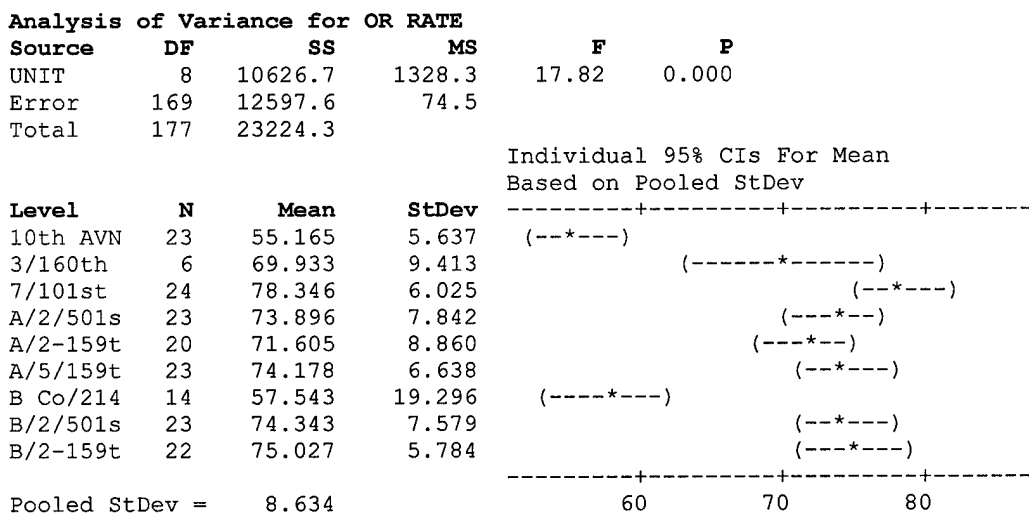
Figure 32: ANOVA of CH-47D OR Rates based on Unit Factor

```
Analysis of Variance for OR RATE
Source      DF        SS        MS        F        P
MACOM        5    10127.7    2025.5    26.60    0.000
Error      172    13096.6      76.1
Total      177    23224.3
                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
Level        N      Mean     StDev   ------+---------+---------+---------+
EUSA        46    74.120     7.629                            (---*--)
FORSCOM     66    75.197     7.365                             (--*--)
SOCOM        6    69.933     9.413                  (-------*--------)
TRADOC      23    55.165     5.637   (----*---)
USAREUR     23    74.178     6.638                         (----*---)
USARPAC     14    57.543    19.296      (-----*-----)
                                      ------+---------+---------+---------+
Pooled StDev =    8.726               56.0      64.0      72.0      80.0
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.00442

Critical value = 4.08

Intervals for (column level mean) - (row level mean)

              EUSA       FORSCOM      SOCOM      TRADOC      USAREUR

FORSCOM      -5.91
              3.76

SOCOM        -6.74       -5.47
             15.11       16.00

TRADOC       12.53       13.94        3.23
             25.38       26.13       26.31

USAREUR      -6.49       -5.08      -15.79      -26.44
              6.37        7.11        7.30      -11.59

USARPAC       8.89       10.25        0.11      -10.91       8.10
             24.26       25.06       24.67        6.16      25.17
```

Figure 33: ANOVA of CH-47D OR Rates based on the MACOM Factor

```
Analysis of Variance for OR RATE
Source      DF        SS        MS         F         P
GROUP        3     7025.9    2342.0     25.16     0.000
Error      174    16198.3      93.1
Total      177    23224.3
                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level        N      Mean     StDev   -------+---------+---------+---------
0           23    55.165     5.637   (----*----)
1           72    74.758     7.619                                (-*--)
2           60    70.252    13.282                       (--*--)
3           23    74.178     6.638                          (----*----)
                                     -------+---------+---------+---------
Pooled StDev =     9.649              56.0      64.0      72.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0103

Critical value = 3.67

Intervals for (column level mean) - (row level mean)

                 0           1           2

    1       -25.590
            -13.596

    2       -21.227       0.130
             -8.946       8.883

    3       -26.397      -5.417     -10.067
            -11.630       6.577       2.214
```

Figure 34: ANOVA of CH-47D OR Rates based on the Group Factor

56

```
Analysis of Variance for OR RATE
Source      DF       SS       MS        F        P
Fleet        1    6319.0   6319.0    65.79    0.000
Error      176   16905.2     96.1
Total      177   23224.3
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N     Mean    StDev  -------+---------+---------+---------
Deployab   155   72.928   10.258                                 (-*-)
Non-Depl    23   55.165    5.637  (-----*-----)
                                  -------+---------+---------+---------
Pooled StDev =    9.801            56.0      63.0      70.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.79

Intervals for (column level mean) - (row level mean)

           Deployab

Non-Depl      13.441
              22.084
```

Figure 35: ANOVA of CH-47D OR Rates based on the Fleet Factor

```
Analysis of Variance for Ag NMCS/
Source      DF       SS       MS        F        P
UNIT         8    26054     3257     5.95    0.000
Error      169    92529      548
Total      177   118583
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N     Mean    StDev  ---+---------+---------+---------+---
10th AVN    23    44.92    26.94                        (-----*-----)
3/160th      6    15.37    26.71    (-----------*----------)
7/101st     24     8.96    13.82    (-----*----)
A/2/501s    23    27.09    28.21            (-----*-----)
A/2-159t    20    19.17    28.38        (-----*-----)
A/5/159t    23    14.08    20.98      (-----*-----)
B Co/214    14    15.00    38.26     (------*-------)
B/2/501s    23     7.83    13.91    (-----*-----)
B/2-159t    22     7.14    11.59    (-----*------)
                                  ---+---------+---------+---------+---
Pooled StDev =   23.40             0        16        32        48
```

Figure 36: ANOVA of Aggregate NMCS down-time for CH-47D based on Unit Factor

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```
Analysis of Variance for Ag NMCS/
Source      DF       SS        MS        F        P
MACOM        5     20038      4008     6.99    0.000
Error      172     98546       573
Total      177    118583

                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N     Mean     StDev   ---+---------+---------+---------+---
EUSA        46     17.46    24.05               (---*---)
FORSCOM     66     11.45    19.32            (--*---)
SOCOM        6     15.37    26.71   (-----------*-----------)
TRADOC      23     44.92    26.94                              (-----*-----)
USAREUR     23     14.08    20.98           (-----*-----)
USARPAC     14     15.00    38.26            (-------*-------)
                                    ---+---------+---------+---------+---
Pooled StDev =    23.94             0        16        32        48
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.00442

Critical value = 4.08

Intervals for (column level mean) - (row level mean)

             EUSA        FORSCOM      SOCOM       TRADOC      USAREUR

FORSCOM      -7.25
             19.28

SOCOM       -27.88      -33.37
             32.07       25.53

TRADOC      -45.10      -50.20      -61.21
             -9.83      -16.75        2.10

USAREUR     -14.25      -19.35      -30.37       10.48
             21.02       14.09       32.94       51.21

USARPAC     -18.62      -23.87      -33.33        6.51       -24.33
             23.54       16.77       34.06       53.33        22.49
```

Figure 37: ANOVA of Aggregate NMCS down-time for CH-47D based on the MACOM Factor

```
Analysis of Variance for Ag NMCS/
Source      DF        SS        MS        F        P
GROUP        3     19888      6629    11.69    0.000
Error      174     98695       567
Total      177    118583
                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level        N      Mean     StDev   --------+---------+---------+--------
0           23     44.92     26.94                          (------*-----)
1           72     11.77     19.83   (---*---)
2           60     16.89     27.65      (---*---)
3           23     14.08     20.98   (-----*------)
                                     --------+---------+---------+--------
Pooled StDev =     23.82                 15        30        45
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.0103

Critical value = 3.67

Intervals for (column level mean) - (row level mean)

                  0            1            2

         1     18.34
               47.95

         2     12.88       -15.92
               43.19         5.69

         3     12.62       -17.11       -12.35
               49.07        12.50        17.96
```

Figure 38: ANOVA of Aggregate NMCS down-time for CH-47D based on the Group Factor

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```
Analysis of Variance for Ag NMCS/
Source      DF       SS       MS       F        P
Fleet        1     19033    19033    33.65    0.000
Error      176     99550      566
Total      177    118583
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N     Mean    StDev    --+---------+---------+---------+----
Deployab   155    14.09    23.30    (--*--)
Non-Depl    23    44.92    26.94                        (-------*--------)
                                    --+---------+---------+---------+----
Pooled StDev =    23.78             12        24        36        48
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.79

Intervals for (column level mean) - (row level mean)

          Deployab

Non-Depl     -41.32
             -20.34
```

Figure 39: ANOVA of Aggregate NMCS down-time for CH-47D based on the Fleet Factor

```
Analysis of Variance for Ag NMCM/
Source      DF        SS       MS       F        P
UNIT         8     496539    62067    18.75    0.000
Error      169     559365     3310
Total      177    1055903
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N     Mean     StDev    ---+---------+---------+---------+---
10th AVN    23    255.17    38.45                              (---*--)
3/160th      6    203.97    54.57             (-------*-------)
7/101st     24    138.32    43.91    (---*---)
A/2/501s    23    132.94    47.61    (---*---)
A/2-159t    20    176.87    48.87          (---*----)
A/5/159t    23    143.28    38.56     (---*---)
B Co/214    14    293.51   133.62                                (----*----)
B/2/501s    23    153.46    54.50       (---*---)
B/2-159t    22    131.97    44.82    (---*---)
                                    ---+---------+---------+---------+---
Pooled StDev =    57.53             120       180       240       300
```

Figure 40: ANOVA for Aggregate NMCM down-time for CH-47D based on Unit Factor

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```
Analysis of Variance for Ag NMCM/
Source      DF        SS        MS        F        P
MACOM        5     467126     93425    27.29    0.000
Error      172     588777      3423
Total      177    1055903
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev   -+---------+---------+---------+-----
EUSA        46    143.20     51.65    (--*--)
FORSCOM     66    147.88     49.07    (--*-)
SOCOM        6    203.97     54.57         (-------*-------)
TRADOC      23    255.17     38.45                     (---*---)
USAREUR     23    143.28     38.56    (---*---)
USARPAC     14    293.51    133.62                          (----*----)
                                   -+---------+---------+---------+-----
Pooled StDev =    58.51          120       180       240       300
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.00442

Critical value = 4.08

Intervals for (column level mean) - (row level mean)

             EUSA       FORSCOM       SOCOM      TRADOC     USAREUR

FORSCOM      -37.1
              27.7

SOCOM       -134.0      -128.1
              12.5        15.9

TRADOC      -155.1      -148.2      -128.6
             -68.9       -66.4        26.2

USAREUR      -43.2       -36.3       -16.7       62.1
              43.0        45.5       138.1      161.7

USARPAC     -201.8      -195.3      -171.9      -95.6     -207.4
             -98.8       -96.0        -7.2       18.9      -93.0
```

Figure 41: ANOVA of Aggregate NMCM down-time for CH-47D based on the MACOM Factor

```
Analysis of Variance for Ag NMCM/
Source      DF        SS        MS        F         P
GROUP        3    207337     69112    14.17     0.000
Error      174    848567      4877
Total      177   1055903
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  --------+---------+---------+--------
0           23    255.17     38.45                          (-----*-----)
1           72    152.56     51.55       (---*--)
2           60    178.27    100.39           (---*--)
3           23    143.28     38.56  (-----*----)
                                   --------+---------+---------+--------
Pooled StDev =    69.83              150       200       250
```

Tukey's pairwise comparisons

```
    Family error rate = 0.0500
Individual error rate = 0.0103

Critical value = 3.67

Intervals for (column level mean) - (row level mean)

                   0            1            2

        1        59.2
                146.0

        2        32.4        -57.4
                121.3          6.0

        3        58.4        -34.1         -9.5
                165.3         52.7         79.4
```

Figure 42: ANOVA of Aggregate NMCM down-time for CH-47D based on the Group Factor

```
Analysis of Variance for Ag NMCM/
Source      DF        SS        MS        F        P
Fleet        1    177085    177085    35.46    0.000
Error      176    878818      4993
Total      177   1055903
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev   ---+---------+---------+---------+---
Deployab   155    161.13     74.13   (--*--)
Non-Depl    23    255.17     38.45                     (------*------)
                                     ---+---------+---------+---------+---
Pooled StDev =     70.66             160       200       240       280

Tukey's pairwise comparisons

     Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.79

Intervals for (column level mean) - (row level mean)

           Deployab

Non-Depl      -125.2
              -62.9
```

Figure 43: ANOVA of Aggregate NMCM down-time for CH-47D based on the Fleet Factor

Regression Analysis

```
The regression equation is
OR RATE = 79.1 - 0.583 Usage/QTY

Predictor          Coef       StDev         T        P
Constant         79.105       2.104     37.60    0.000
Usage/QT        -0.5825      0.1333     -4.37    0.000

S = 10.91       R-Sq = 9.8%       R-Sq(adj) = 9.3%
```

Figure 44: Regression Model of Usage as the Predictor of CH-47D OR Rates

```
The regression equation is
Trans OR = 50.8 - 0.340 Usage/QTY

Predictor         Coef        StDev           T         P
Constant        50.811        1.245       40.80     0.000
Usage/QT       -0.34020      0.07888       -4.31     0.000

S = 6.458        R-Sq = 9.6%        R-Sq(adj) = 9.0%
```

Figure 45: Regression Model of Usage as the Predictor of Transformed CH-47D OR Rates

```
The regression equation is
Ag NMCS/QTY = 7.86 + 0.702 Usage/QTY

Predictor         Coef        StDev           T         P
Constant         7.863        4.935        1.59     0.113
Usage/QT        0.7023       0.3126        2.25     0.026

S = 25.59        R-Sq = 2.8%        R-Sq(adj) = 2.2%
```

Figure 46: Regression Model of Aggregate NMCS down-time as the Predictor of CH-47D OR Rates

```
The regression equation is
Ag NMCM/QTY = 122 + 3.51 Usage/QTY

Predictor         Coef        StDev           T         P
Constant        122.23        14.34        8.52     0.000
Usage/QT        3.5100       0.9084        3.86     0.000

S = 74.37        R-Sq = 7.8%        R-Sq(adj) = 7.3%
```

Figure 47: Regression Model of Aggregate NMCM down-time as the Predictor of CH-47D OR Rates

Time-Series Analysis

Trend Analysis for CH-47D Deployable Unit OR Reports

Linear Trend Model
Yt = 75.9649 - 0.260522*t
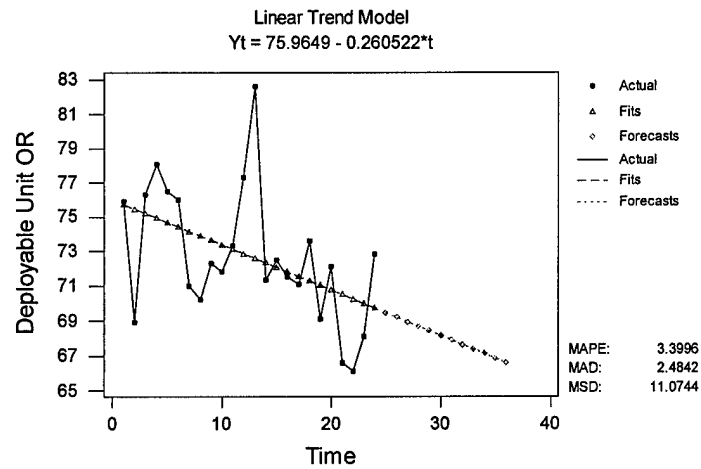
MAPE: 3.3996
MAD: 2.4842
MSD: 11.0744

Figure 48: Trend Analysis for CH-47D Deployable Unit OR Reports

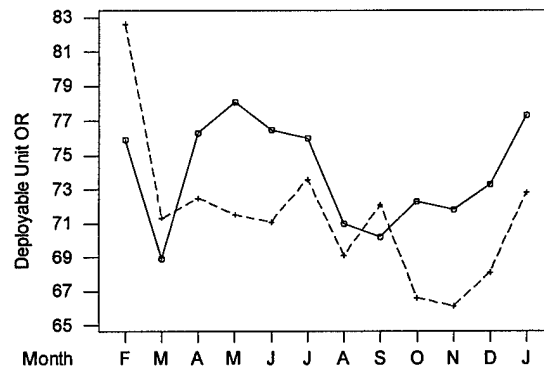Overlay of '96 & '97 Deployable CH-47 Unit OR Reports

Figure 49: Time-Series Plot of '96 & '97 Deployable Ch-47D Unit OR Reports

M9 ACE Data Analysis Continued

Analysis of Variance

```
Analysis of Variance for Ag NMCS/QTY
Source      DF       SS       MS       F       P
UNIT        19    237.04    12.48    4.60    0.000
Error      409   1108.67     2.71
Total      428   1345.70
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N    Mean     StDev    -------+---------+---------+---------
10th EN     24    1.312    1.044      (-----*----)
11th EN     24    2.050    1.187          (----*-----)
168th EN    18    3.367    1.877                    (-----*-----)
16th EN     20    2.440    1.637             (-----*-----)
1st EN B    25    2.744    1.641               (-----*----)
1st EN B    24    3.604    2.042                       (----*-----)
20th EN     23    2.465    2.169            (-----*----)
23rd EN     18    3.239    1.434                   (-----*-----)
299th EN    22    2.068    1.679          (-----*-----)
2nd EN B    23    1.304    0.771     (-----*----)
317th EN    20    2.200    0.995           (-----*-----)
40th EN     19    2.168    1.558           (-----*-----)
43rd EN     23    3.213    2.652                  (-----*----)
44th EN     14    2.971    1.213                (------*------)
58th EN     20    2.840    2.996                (-----*-----)
70th EN     24    2.271    1.325           (-----*----)
82nd EN     23    2.617    1.262              (-----*----)
8th EN B    23    1.591    1.357        (----*-----)
91st EN     22    1.055    0.978    (-----*-----)
9th EN B    20    3.555    1.173                     (-----*-----)
                                    -------+---------+---------+---------
Pooled StDev =     1.646              1.2       2.4       3.6
```

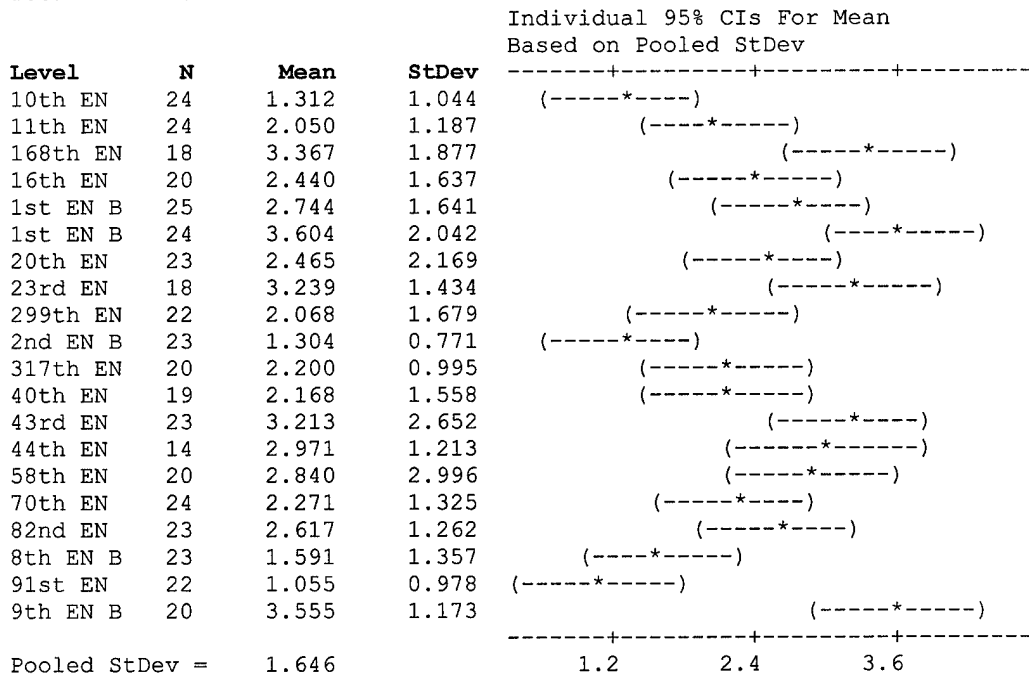**Figure 50: ANOVA of Aggregate NMCS down-time for M9 OR Reports based on the Unit Factor**

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```
Analysis of Variance for Ag NMCS/
Source      DF        SS        MS        F        P
MACOM        4      34.10      8.53     2.76    0.028
Error      424    1311.60      3.09
Total      428    1345.70
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level        N      Mean     StDev    -+---------+---------+---------+-----
EUSA        37     1.935     1.252     (-------*-------)
FORSCOM    247     2.276     1.807             (---*--)
OTHER       20     2.840     2.996               (----------*----------)
TRADOC      25     2.744     1.641             (---------*---------)
USAREUR    100     2.796     1.479                   (----*----)
                                       -+---------+---------+---------+-----
Pooled StDev =     1.759             1.40      2.10      2.80      3.50
```

Tukey's pairwise comparisons

      Family error rate = 0.0500
Individual error rate = 0.00661

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

```
              EUSA         FORSCOM       OTHER        TRADOC

FORSCOM      -1.187
              0.505

OTHER        -2.237       -1.680
              0.427        0.552

TRADOC       -2.052       -1.475       -1.344
              0.434        0.540        1.536

USAREUR      -1.785       -1.089       -1.132       -1.125
              0.063        0.049        1.220        1.021
```

Figure 51: ANOVA of Aggregate NMCS for M9 OR Reports based on the MACOM Factor

```
Analysis of Variance for Ag NMCS/QTY
Source      DF        SS        MS        F        P
Group        4      66.71     16.68     5.53    0.000
Error      424    1278.99      3.02
Total      428    1345.70
                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level        N      Mean     StDev   --+---------+---------+---------+----
0           45     2.609     1.627          (-------*--------)
1          159     1.982     1.724   (---*----)
2           77     2.308     1.631      (-----*------)
3          128     2.905     1.588                 (----*----)
9           20     2.840     2.996          (-----------*------------)
                                     --+---------+---------+---------+----
Pooled StDev =    1.737            1.80      2.40      3.00      3.60
```

Tukey's pairwise comparisons

```
     Family error rate = 0.0500
Individual error rate = 0.00661

Critical value = 3.86

Intervals for (column level mean) - (row level mean)

                   0          1          2          3

    1         -0.173
               1.428

    2         -0.588     -0.984
               1.191      0.332

    3         -1.117     -1.486     -1.281
               0.526     -0.360      0.087

    9         -1.505     -1.983     -1.722     -1.075
               1.043      0.266      0.658      1.205
```

Figure 52: ANOVA of Aggregate NMCS down-time for M9 OR Reports based on the Group Factor

```
Analysis of Variance for Ag NMCS/QTY
Source      DF        SS        MS         F         P
Fleet        1      6.71      6.71      2.14     0.144
Error      427   1339.00      3.14
Total      428   1345.70
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev   -------+---------+---------+---------
Deployab   384     2.379     1.698   (-----*-----)
Non-Depl    45     2.787     2.312       (----------------*----------------)
                                    -------+---------+---------+---------
Pooled StDev =     1.771               2.40      2.70      3.00

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.0500

Critical value = 2.78

Intervals for (column level mean) - (row level mean)

          Deployab

Non-Depl      -0.956
               0.140
```

Figure 53: ANOVA of Aggregate NMCS down-time for M9 OR Reports based on the Fleet Factor

It must be noted that Figure 53 represents the only ANOVA based on the fleet factor that did not indicate a significant difference between deployable and non-deployable units. We hypothesized that this may be due to the extraordinary efforts taken by O/DCSLOG to assist M9 ACE units in the attainment of the current goal of 90% FMC.

Appendix D: Comparison of Proposed ES Standards & Current OR Goals

Rating/ Standards	R1	R2	R3	R4
Current	100-75%	74-60%	59-50%	< 50%
Proposed	100-70%	67-69%	64-66%	< 64%

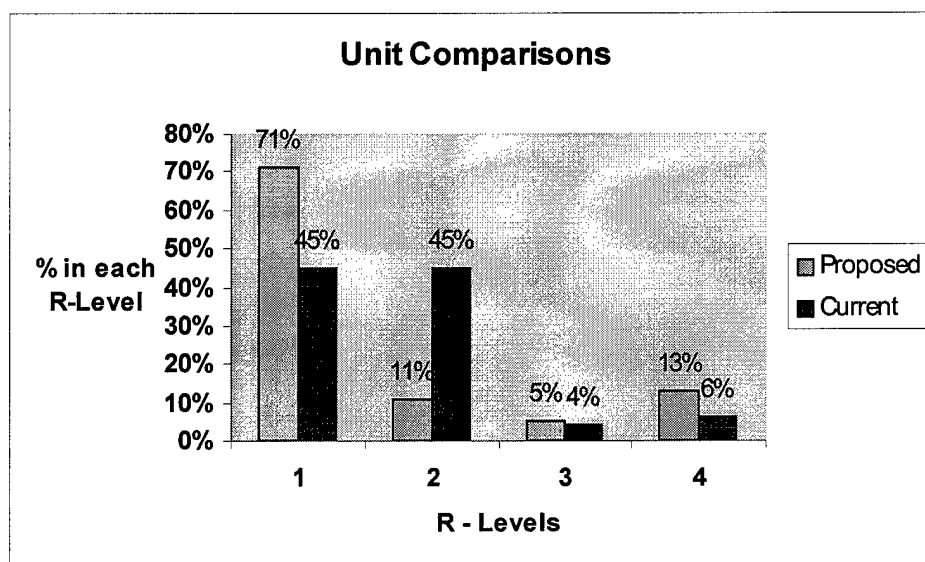Table 16: Comparison of Current and Proposed CH-47D Standards

Unit Comparisons

Figure 54: Comparison of Evaluations of 1997 "Deployable" CH-47D Unit OR Reports using Current and Proposed Standards

Rating/ Standards	R1	R2	R3	R4
Current	100-90%	89-70%	69-60%	< 60%
Proposed	100-91%	90%	89%	< 89%

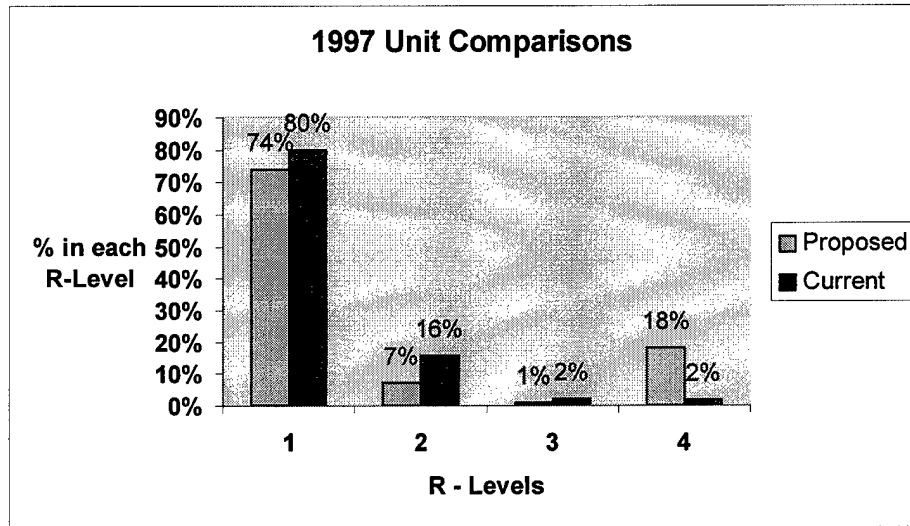**Table 17: Comparison of Current and Proposed M1A1 Standards**

Figure 55: Comparison of Evaluations of 1997 "Deployable" M1A1 Unit OR Reports using Current and Proposed Standards

The proposed M1A1 standards are the only standards that were increased from the current leadership directed standards. The result of raising the standard is evident in Figure 55. Instead of increasing the number of units categorized as R-1, we have now decreased the R-1 units. However, just as with the analysis of the other equipment, we increased the number of R-4 units. These R-4 units represent the units that should be investigated for their "out of control" OR report.

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Appendix E: References

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